DISEÑO Y FABRICACIÓN DE UN BANCO DE PRUEBA MÓVIL PARA LÍQUIDOS PENETRANTES Y PARTICULAS MAGNETICAS EN EL ÁREA DE ENSAYOS NO DESTRUCTIVOS

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PROYECTO DE GRADO PARA OPTAR AL TÍTULO DE TECNÓLOGO EN MECÁNICA

ASESOR
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INSTITUCIÓN UNIVERSITARIA PASCUAL BRAVO
FACULTAD DE INGENIERIA
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Medellín, 31 de Mayo de 2014

DEDICATORIA

Este proyecto va dedicado a nuestros padres, hermanos, profesores y amigos que con su apoyo incondicional han hecho posible, que nuestras vidas estén llenas de gozo y satisfacción personal en una lucha constante por sacar adelante nuestras carreras.

AGRADECIMIENTOS

En primera instancia agradecemos a nuestros padres por habernos brindado la oportunidad de estudiar en esta Institución, por su lucha inagotable en los momentos difíciles donde se veía comprometida nuestra estancia en la misma. De igual manera agradecemos a todos los profesores por compartir sus conocimientos sin esperar nada a cambio, pero con la convicción de ver en nosotros los profesionales del mañana.

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GLOSARIO

GRIETA: Abertura o quiebra que surge de forma natural en alguna superficie.

FUSIÓN: Unión de dos o más partes por la acción del calor.

INSPECCIÓN: hace referencia a la acción y efecto de inspeccionar (examinar, investigar, revisar). Se trata de una exploración física que se realiza principalmente a través de la vista. El objetivo de una inspección es hallar características físicas significativas para determinar cuáles son normales y distinguirlas de aquellas características anormales.

CATÓDICO: Relativo al electrodo negativo.

EMULSIÓN: Líquido que tiene en suspensión pequeñísimas partículas de sustancias insolubles en agua.

BOBINA: la bobina por su forma (espiras de alambre arrollados) almacena energía en forma de campo magnético. Todo cable por el que circula una corriente tiene a su alrededor un campo magnético generado por la mencionada corriente, siendo el sentido de flujo del campo magnético el que establece la "**ley de la mano derecha"** .Al estar la bobina hecha de espiras de cable, el campo magnético circula por el centro de la bobina y cierra su camino por su parte exterior.

PERMEABILIDAD: es la capacidad que tiene un material de permitirle que un flujo magnético lo atraviese sin alterar su estructura interna. Se afirma que un material

es permeable si deja pasar a través de él una cantidad apreciable de fluido en un tiempo dado, es impermeable si la cantidad de fluido es despreciable.[1]

[1] Referencia tomada de: Algunas definiciones de ingeniería. Recuperado el (15 de Abril de 2014) disponible en: http://www.wordreference.com/definicion.

RESUMEN

Este trabajo se basa en la utilización de ensayos no destructivos como lo son los líquidos penetrantes y las partículas magnéticas para detectar discontinuidades superficiales y sub-superficiales en materiales, soldaduras, componentes y partes fabricadas. La falla es el daño de una pieza que no le permite continuar en servicio, causando la sustitución prematura de los componentes. Prematuro por la sustitución de la pieza antes de haber alcanzado su vida útil especificada en el diseño. La falla de los materiales puede producirse por defectos de fabricación, errores de operación o inadecuada selección de materiales.

Con el diseño y fabricación de este banco móvil de pruebas se pretende crear una herramienta que permita a los estudiantes de la Institución conocer más a fondo sobre estos ensayos, ensayos de gran utilidad en la industria tanto en sus procesos de fabricación como en equipos y elementos en servicio. Dicha herramienta constituye un avance significativo en afianzar a los estudiantes a los procesos reales en la industria.

Palabras Claves:

Ensayos no destructivos, líquidos penetrantes, partículas magnéticas, grieta, falta de fusión, porosidad, banco móvil.

ASBTRACT

This work is based on the utilization of not destructive tests (essays) like it they are the penetrating liquids and the magnetic particles to detect superficial and sub-superficial discontinuities in materials, welds, components and made parts. The fault is the hurt (damage) of a piece that does not allow him (her) to continue in service, causing the premature substitution of the components. Premature baby for the substitution of the piece before having reached his (her, your) useful life specified in the design. The fault of the materials can take place (be produced) for faults of manufacture, mistakes of operation or inadequate selection of materials.

With the design and manufacture of this mobile bank of tests (proofs) it is tried to create a tool that allows to the students of the Institution to know more thoroughly on these tests (essays), tests (essays) of great usefulness (utility) in the industry both in his (her, your) manufacturing processes and in equipments (teams) and elements in service. The above mentioned tool constitutes a significant advance in guaranteeing the students to the royal (real) processes in the industry.

Keyword:

Nondestructive testing (essays), penetrating liquids, magnetic particles, crack, lack (mistake) of merger, porosity, mobile bank.

INTRODUCCIÓN

Los Ensayos No Destructivos (END) aparecen como una expresión de la actividad inteligente del hombre en sus primeros deseos de dominar y transformar la naturaleza.

El propósito de estos ensayos es detectar discontinuidades superficiales e internas en materiales, soldaduras, componentes y partes fabricadas. La falla es el daño de una pieza que no le permite continuar en servicio, causando la sustitución prematura de los componentes. Prematuro por la sustitución de la pieza antes de haber alcanzado su vida útil especificada en el diseño. La falla de los materiales puede producirse por defectos de fabricación, errores de operación o inadecuada selección de materiales.

Cada día los proyectos de ingeniería tienen un objetivo principal: garantizar la seguridad e integridad de las estructuras de acero soldadas, convirtiéndola en una de las herramientas más importantes en el control de calidad (para evitar una eventual falla). Por eso la necesidad de definir los procedimientos de soldadura necesarios para la unión soldada de los distintos aceros conocidos en la industria.

La realización de este banco de prueba constituye una herramienta excepcional para la enseñanza de estos Ensayos no Destructivos, ensayos de gran uso a nivel industrial, y que además, contribuye a la Institución Universitaria Pascual Bravo un adelanto en su afán por mejorar la competitividad y su nivel académico.

El objetivo con el cual se pretende realizar este trabajo es brindarles a los estudiantes de la Institución mayor facilidad de aprendizaje y un acercamiento a los procesos industriales reales.

1 DESCRIPCIÓN DEL PROBLEMA

1.1 PLANTEAMIENTO DEL PROBLEMA

La Institución Universitaria Pascual Bravo cuenta con laboratorios para ofrecerles a los estudiantes alternativas de realizar sus prácticas en los distintos ámbitos durante su preparación académica.

El problema se encuentra en que los laboratorios de soldadura y resistencia de materiales de dicha Institución no cuentan con un banco de pruebas para ensayos no destructivos, como lo son los líquidos penetrantes y las partículas magnéticas, ensayos que cobran gran importancia a nivel industrial en el mejoramiento de los procesos de uniones soldadas y en la detección de piezas y componentes defectuosos.

1.2 FORMULACIÓN DEL PROBLEMA

¿Será de gran utilidad en el proceso de enseñanza de los Ensayos Destructivos?

¿Aumentará la competitividad de la Institución?

¿Su funcionamiento se verá afectado por factores propios de la Institución?

2 JUSTIFICACIÓN

El banco de pruebas para realizar los ensayos de líquidos penetrantes y partículas magnéticas, constituye una estrategia novedosa educativa y tecnológica que servirá como apoyo para el docente en la enseñanza de los materiales y sus propiedades, de la verificación de la calidad de los procesos de soldados, por medio de los métodos de Ensayos No Destructivos, y en los estudiantes el aprendizaje de la misma. Este banco de pruebas puede ser visto como una posible solución a escasez de herramientas y de prácticas, indispensables para la formación de los estudiantes.

Con éste proyecto se pretende que los estudiantes de Mecánica y afines, tengan la opción de un aprendizaje teórico – práctico en donde encuentren las herramientas necesarias que los lleve a la experimentación, en un equipo e instrumentos reales para corroborar la teoría.

El proceso de enseñanza y de aprendizaje se sustenta en un proceso comunicacional donde alguien quiere compartir al otro algún concepto que sea incorporado por éste y que le signifique posteriormente una ayuda para resolver algún problema y al mismo tiempo éste último retribuya al emisor inicial para que se construya un ciclo de cooperación mutua, donde uno forme y acompañe y otro aprenda y crezca.

Finalmente, la Institución tendrá un mejor nivel académico y su imagen no se verá afectada, ya que los estudiantes no necesitarán desplazarse a otras instituciones. Es válido apuntar que, a futuro, la Institución podrá ofrecer este servicio a otras entidades educativas y empresas.

3 OBJETIVOS

3.1 GENERAL

Diseñar y fabricar un banco de prueba móvil para líquidos penetrantes y partículas magnéticas en el área de ensayos no destructivos para la Institución Universitaria Pascual Bravo.

3.2 ESPECÍFICOS

- Identificar las normas y requerimientos que regulan la realización de los ensayos de líquidos penetrantes y partículas magnéticas.

- Seleccionar los instrumentos y herramientas necesarias para la fabricación del banco de pruebas móvil.

- Realizar manuales de procedimientos de los ensayos mencionados.

4 MARCO TEÓRICO

4.1 LOS ENSAYOS NO DESTRUCTIVOS

Se denomina ensayo no destructivo (también llamado END, o en inglés NDT de non destructive testing) a cualquier tipo de prueba practicada a un material que no altere de forma permanente sus propiedades físicas, químicas, mecánicas o dimensionales. Los ensayos no destructivos implican un daño imperceptible o nulo.

Se denomina así a toda prueba que se realice sobre un material sin afectarlo metalúrgicamente no mecánicamente, se realizan con el fin de determinar el estado geométrico, mecánico o químico de la pieza para verificar si cumple con las reglas de aplicación que correspondan, ejemplo de ellos son: Radiografiado de cordones de soldadura (rayos x), tintas penetrantes, partículas magnéticas, medición de espesores por medios ultrasónicos.

4.2 ANTECEDENTES

Los ensayos no destructivos se han practicado por muchas décadas. Se tiene registro desde 1868 cuando se comenzó a trabajar con campos magnéticos. Uno de los métodos más utilizados fue la detección de grietas superficiales en ruedas y ejes de ferrocarril. Las piezas eran sumergidas en aceite, y después se limpiaban y se esparcían con un polvo. Cuando una grieta estaba presente, el aceite que se había filtrado en la discontinuidad, mojaba el polvo que se había esparcido, indicando que el componente estaba dañado. Esto condujo a formular nuevos

aceites que serían utilizados específicamente para realizar éstas y otras inspecciones, y esta técnica de inspección ahora se llama prueba por líquidos penetrantes (PT).

Sin embargo con el desarrollo de los procesos de producción, la detección de discontinuidades ya no era suficiente. Era necesario también contar con información cuantitativa sobre el tamaño de la discontinuidad, para utilizarla como fuente de información, con el fin de realizar cálculos matemáticos y poder predecir así la vida mecánica de un componente. Estas necesidades, condujeron a la aparición de la Evaluación No Destructiva (NDE) como nueva disciplina. A raíz de esta revolución tecnológica se suscitarían en el campo de las PND una serie de acontecimientos que establecerían su condición actual.

En el año de 1941 se funda la Sociedad Americana para Ensayos No Destructivos (ASNT por sus siglas en inglés), la cual es la sociedad técnica más grande en el mundo de pruebas no destructivas. Esta sociedad es promotora del intercambio de información técnica sobre las PND, así como de materiales educativos y programas. Es también creadora de estándares y servicios para la Calificación y Certificación de personal que realiza ensayos no destructivos, bajo el esquema americano.

A continuación se proporcionan una serie de fechas relacionadas con acontecimientos históricos, descubrimientos, avances y aplicaciones, de algunas pruebas no destructivas.

- 1868 Primer intento de trabajar con los campos magnéticos.
- 1879 David Hughes establece un campo de prueba.
- 1879 David Hughes estudia las Corrientes Eddy.
- 1895 Wilhelm Röntgen estudia el tubo de rayos catódicos.
- 1895 Wilhelm Röntgen descubre los Rayos X.

- 1896 Henri Becquerel descubre los Rayos gamma.
- 1900 Inicio de los líquidos penetrantes en FFCC.
- 1911 ASTM establece el comité de la técnica de MT.
- 1928 Uso industrial de los campos magnéticos.
- 1930 Theodore Zuschlag patenta las Corrientes Eddy.
- 1931 Primer sistema industrial de Corrientes Eddy instalado.
- 1941 Aparecen los líquidos fluorescentes.
- 1945 Dr. Floy Firestone trabaja con Ultrasonido.
- 1947 Dr. Elmer Sperry aplica el UT en la industria.

La entidad que reúne a todas las instituciones debidamente constituidas es el Comité Internacional de Ensayos No Destructivos (ICNDT, por sus siglas en inglés) con sede en Viena.

La globalización en los mercados mundiales ha marcado el desarrollo de los ensayos no destructivos, los cuales tienen ya un alcance en cada rincón del planeta, y actualmente existen sociedades de ensayos no destructivos en la mayoría de los países como por ejemplo, La Sociedad Argentina de Ensayos No Destructivos (AAENDE), El Instituto Australiano para Ensayos No Destructivos (AINDT), La Sociedad Austriaca de Ensayos No Destructivos (OGFZP), La Asociación Belga de Ensayos No Destructivos (BANT), La Sociedad Brasileña de Ensayos No Destructivos (ABENDE), La Sociedad Canadiense de Ensayos No destructivos (CSNDT), La Sociedad China para Ensayos No Destructivos (ChSNDT), El Instituto Mexicano de Ensayos No Destructivos A.C. (IMENDE A.C., Asociación Mexicana de Ensayos No Destructivos (AMEXEND A.C.).[2]

[2] Referencia tomada de: Ensayos no Destructivos. De la página 21 a la 23. Recuperado el (26 de Abril de 2014) disponible en: http://ejemplon.com/ensayos-no-destructivos/.

4.3 OBJETIVOS DE LOS ENSAYOS NO DESTRUCTIVOS

El propósito de estos ensayos es detectar discontinuidades superficiales e internas en materiales, soldaduras, componentes e partes fabricadas.

Los métodos de END, permiten el control del 100% de una producción y pueden obtener información de todo el volumen de una pieza, con lo que contribuyen a mantener un nivel de calidad uniforme, con la consiguiente conservación y aseguramiento de la calidad funcional de los sistemas y elementos. Además colaboran en prevenir accidentes, ya que se aplican en mantenimiento y en vigilancia de los sistemas a lo largo del servicio.

Por otra parte proporcionan beneficios económicos directos e indirectos. Beneficios directos, por la disminución de los costos de fabricación, al eliminar en las primeras etapas de fabricación, los productos que serían rechazados en la inspección final, y el aumento de la productividad, por reducirse el porcentaje de productos rechazados en dicha inspección final.

Entre los beneficios indirectos se pueden citar su contribución a la mejora de los diseños, por ejemplo, demostrando la necesidad de realizar un cambio de diseño de molde en zonas críticas de piezas fundidas o también contribuyendo en el control de procesos de fabricación.

4.3 TIPOS DE PRUEBAS

4.4.1 Pruebas no destructivas superficiales

Estas pruebas proporcionan información acerca de la sanidad superficial de los materiales inspeccionados. Los métodos de PND superficiales son:

- **Inspección Visual (VT)**

Esta es una técnica que requiere de una gran cantidad de información acerca de las características de la pieza a ser examinada, para una aceptada interpretación de las posibles indicaciones. Esta ampliamente demostrado que cuando se aplica correctamente como inspección preventiva, detecta problemas que pudieran ser mayores en los pasos subsecuentes de producción o durante el servicio de la pieza.

Foto 1. Medición de altura de filete con galgas AWS.

- **Líquidos penetrantes (PT)**

La inspección por líquidos penetrantes es un tipo de ensayo no destructivo que se utiliza para detectar e identificar discontinuidades presentes en la superficie de los materiales examinados. Generalmente se emplea en aleaciones no ferrosas, aunque también se puede utilizar para la inspección de materiales ferrosos cuando la inspección por partículas magnéticas es difícil de aplicar. En algunos casos se puede utilizar en materiales no metálicos. El procedimiento consiste en aplicar un líquido coloreado o fluorescente a la superficie en estudio, el cual penetra en cualquier discontinuidad que pudiera existir debido al fenómeno de capilaridad. Después de un determinado tiempo se remueve el exceso de líquido y se aplica un revelador, el cual absorbe el líquido que ha penetrado en las discontinuidades y sobre la capa del revelador se delinea el contorno de éstas.

Las aplicaciones de esta técnica son amplias, y van desde la inspección de piezas críticas como son los componentes aeronáuticos hasta los cerámicos como las vajillas de uso doméstico. Se pueden inspeccionar materiales metálicos, cerámicos vidriados, plásticos, porcelanas, recubrimientos electroquímicos, entre otros. Una de las desventajas que presenta este método es que sólo es aplicable a defectos superficiales y a materiales no porosos.

Foto 2. Inspección con líquidos penetrantes a tubería de acueducto American Pipe en acero al carbono.

- **Partículas Magnéticas (MT)**

La prueba de partículas magnéticas es un método de prueba no destructivo para la detección de imperfecciones sobre o justamente debajo de la superficie de metales ferrosos que también se puede aplicar en soldadura. Es una técnica rápida y confiable para detección y localización de grietas superficiales.

Un flujo magnético es enviado a través del material y en el lugar de la imperfección se forma un campo de fuga que atrae el polvo de hierro que se rocía sobre la superficie, así la longitud de la imperfección puede ser determinada de forma muy confiable. Criterios de aceptación definen si la indicación es o no aceptable, es decir si se trata de un defecto o no.

En el ensayo no destructivo de partículas magnéticas inicialmente se somete a la pieza a inspeccionar a una magnetización adecuada y se espolvorea partículas finas de material ferromagnético. Es un tipo de ensayo no destructivo que permite

detectar discontinuidades superficiales y sub-superficiales en materiales ferro-magnéticos. Se selecciona usualmente cuando se requiere una inspección más rápida con los líquidos penetrantes.

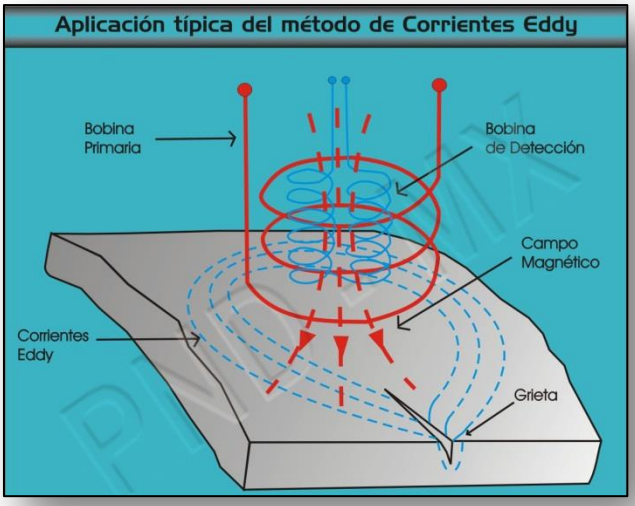
Foto 3. Inspección con partículas magnéticas a tubería de acueducto American Pipe en acero al carbono.

- **Electromagnetismo (ET)**

El electromagnetismo anteriormente llamado corrientes de Eddy o de Foucault se emplea para inspeccionar materiales que sean electro conductores, siendo especialmente aplicable aquellos que no son ferromagnéticos. La inspección por corriente EDDY, está basada en el efecto de inducción electromagnética. Ver figura 1.

En el caso de utilizar VT y PT se tiene la limitante para detectar únicamente discontinuidades superficiales (abiertas a la superficie); y con MT y ET se tiene la posibilidad de detectar tanto discontinuidades superficiales como sub-superficiales (las que se encuentran debajo de la superficie pero muy cercanas a ella).

Figura 1. Aplicación típica del método de corrientes de Eddy.



4.4.2 Pruebas no destructivas de hermeticidad

Estas pruebas proporcionan información del grado en que pueden ser contenidos los fluidos en recipientes, sin que escapen a la atmósfera o queden fuera de control. Los métodos de PND de hermeticidad son:

- Pruebas de Fuga.
- Pruebas por Cambio de Presión (Neumática o hidrostática).
- Pruebas de Burbuja.
- Pruebas por Espectrómetro de Masas Pruebas de Fuga con Rastreadores de Halógeno.

4.4.3 Pruebas no destructivas volumétricas

Estas pruebas proporcionan información acerca de la sanidad interna de los materiales inspeccionados. Los métodos de PND volumétricos son:

- **Radiografía Industrial (RT)**

Una radiografía es una imagen registrada en una placa o película fotográfica. La imagen se obtiene al exponer dicha placa o película a una fuente de radiación de alta energía, comúnmente rayos X o radiación gamma procedente de isótopos radiactivos (Iridio 192, Cobalto 60, Cesio 137, entre otros). Al interponer un objeto entre la fuente de radiación y la placa o película las partes más densas aparecen con un tono más o menos gris en función inversa a la densidad del objeto. Por ejemplo: si la radiación incide directamente sobre la placa o película, se registra un tono negro. Sus usos pueden ser tanto médicos, para detectar fisuras en huesos, como industriales en la detección de defectos en materiales y soldaduras tales como grietas, poros, "rechupes", entre otros.

Figura 2. Aplicación típica del método de radiografía.

La radiografía industrial de Molgilner ensayo no destructivo de tipo físico utilizado para inspeccionar materiales en busca de discontinuidades macroscópicas y variaciones en su estructura interna. La radiación electromagnética de onda corta tiene la propiedad de poder penetrar diversos materiales sólidos, por lo que al utilizarla se puede generar una imagen de la estructura interna del material examinado. El principio de esta técnica consiste en que cuando la energía de los

rayos X o gamma atraviesa una pieza, sufre una atenuación que es proporcional al espesor, densidad y estructura del material inspeccionado. Posteriormente, la energía que logra atravesar el material es registrada utilizando una placa fotosensible, de la cual se obtiene una imagen del área en estudio.

Los rayos x son una forma electromagnética (como una luz) que contiene una gran energía y por ello, es posible que penetre en el cuerpo humano, produciendo así, una imagen en una placa de fotografía durante este paso, las radiaciones se modifican, entonces, al pasar por estructuras de gran densidad como el hueso, la imagen que se producirá en la placa será de color blanco y si atraviesa estructuras con aire se formara una imagen de color negro. Los colores dependerán de la densidad de las estructuras.

- Se basa en la absorción diferencial de la radiación por los materiales.
- Peligrosa para los seres vivos.
- Da un registro permanente.[3]

- **Ultrasonido industrial (UT)**

La inspección por ultrasonido se define como un procedimiento de inspección no destructivo de tipo mecánico, y su funcionamiento se basa en la impedancia acústica, la que se manifiesta como el producto de la velocidad máxima de propagación del sonido entre la densidad del material. Cuando se inventó este procedimiento, se medía la disminución de intensidad de energía acústica cuando se hacían viajar ondas supersónicas en un material, requiriéndose el empleo de un emisor y un receptor.

[3] Referencia tomada de: FRANCO GIMENO, Jose. Ensayos no destructivos par la industria y la construcción. España: Prensas universitarias de Zaragoza, 2002. De la pagina 23 a la 31. Recuperado el (05 de Mayo de 2014) disponible en: http://www.casadellibro.com/libro-ensayos-no-destructivos-para-industria-y-construccion/9788477335221/672646.

Actualmente se utiliza un único aparato que funciona como emisor y receptor, basándose en la propiedad característica del sonido de reflejarse al alcanzar una interface acústica. Los equipos de ultrasonido que se utilizan actualmente permiten detectar discontinuidades superficiales, sub-superficiales e internas, dependiendo del tipo de palpado utilizado y de las frecuencias que se seleccionen dentro de un rango que va desde 0.25 hasta 25 MHz.

Las ondas ultrasónicas son generadas por un cristal o un cerámico piezoeléctrico denominado transductor y que tiene la propiedad de transformar la energía eléctrica en energía mecánica y viceversa. Al ser excitado eléctricamente el transductor vibra a altas frecuencias generando ultrasonido. Las vibraciones generadas son recibidas por el material que se va a inspeccionar, y durante el trayecto la intensidad de la energía sónica se atenúa proporcionalmente a la distancia del recorrido. Al alcanzar la frontera del material, el haz sónico es reflejado, y se recibe el eco por otro (o el mismo) transductor. Su señal es filtrada e incrementada para ser enviada a un osciloscopio de rayos catódicos.

Foto 4. Inspección de materiales con ultrasonido industrial.

- **Emisión Acústica (AE)**

Es un método de inspección de carácter mecánico y se basa en la emisión de pulsos definidos que se propagan en el material de forma radial a la velocidad de sonido .Con lo anterior se detectan y miden, a través de instrumentos de AET, las ondas elásticas que se crea en forma espontánea en los puntos de un material que se somete a esfuerzo físico y al que se deforma de manera plástica. Estos métodos permiten la detección de discontinuidades internas y sub-superficiales, así como bajo ciertas condiciones, la detección de discontinuidades superficiales.[4]

4.5 MÈTODOS PARA REALIZAR Y APLICAR EL ENSAYO DE LIQUIDOS PENETRANTES

4.5.1 Normas de referencia

- Código ASME Sección V, Artículos 6.
- ANSI / ASTM E-1417 Práctica Recomendada para el Examen por Líquidos Penetrantes.
- ASNT SNT-TC-1A - Recommended Practice for Personal Qualification and Certification in Nondestructive Testing.

[4] Referencia tomada de: Ensayos no Destructivos. De la página 32 a la 33. Recuperado el (05 de Mayo de 2014) disponible en: http://chirinossilvaroger.files.wordpress.com/2012/05/trabajo-de-ensayos-no-destructivos.pdf.

4.5.2 Inspección por líquidos penetrantes

Basados en el principio de capilaridad de los líquidos que permite su penetración y retención en aberturas estrechas como son: fisuras, poros o huecos.

Los métodos de inspección por líquidos penetrantes son dos según ASTM E-1417: el fluorescente y el coloreado.

- **Líquidos penetrantes fluorescentes**

Son los que incorporan en su composición un pigmento fluorescente, visible bajo la iluminación de luz negra adecuada.

- **Líquidos penetrantes coloreados**

Contienen pigmentos fuertemente coloreados en disoluciones apropiadas.

Según la forma en que puede ser eliminado el exceso de líquido penetrante se pueden clasificar en:

- **Líquidos penetrantes auto-emulsificables:** son los que se eliminan directamente con agua debido a que se incorporan en su composición productos emulsificables.

- **Líquidos penetrantes post-emulsificables:** este tipo de penetrantes llevan una etapa intermedia entre la penetración y el lavado con agua, y es la aplicación del emulsificador, porque sin ello este tipo de líquidos no es lavable con agua. De mayor sensibilidad en la detección de pequeñas discontinuidades.

- **Líquidos penetrantes removibles con solventes:** El exceso de penetrante deberá ser eliminado hasta donde sea posible frotando la superficie con una tela o papel absorbente humedecido con un solvente adecuado, evitando el exceso de solvente pare evitar sacar el penetrante que hay dentro de las discontinuidades.

4.5.3 Criterios para la selección del líquido penetrante

El criterio de selección del método se hará de acuerdo a los requerimientos establecidos por la norma aplicada y basado en el criterio, experiencias previas y la condición del equipo a ser inspeccionado según tablas 1 y 2.

- **Control de contaminantes**

Requeridos para todos los materiales de líquidos penetrantes usados en aleaciones de níquel, aceros inoxidables austeníticos y titanio, cuando se usen en aleaciones de titanio se deberá controlar el contenido de azufre, cuando se use en aceros inoxidables o titanio se deberá controlar el contenido de cloro y flúor

Tabla 1. Selección del penetrante fluorescente autoemulsionable.

PENETRANTE FLUORESCENTE AUTOEMULSIONABLE	
VENTAJAS	**LIMITACIONES**
La fluorescencia le proporciona muy buena visibilidad.	El lavado excesivo puede disminuir la sensibilidad.

Se puede lavar directamente con agua	El anodizado puede afectar su sensibilidad.
Se puede utilizar en superficies rugosas.	El cromado puede afectar su sensibilidad.
Gran economía de tiempo en el proceso.	No es adecuado para discontinuidades de poca profundidad.
Bueno para una amplia gama de discontinuidades.	Precisa de cámara oscura, dotada de luz negra, para observación.

Tabla 2. Selección del penetrante de contraste coloreado.

PENETRANTE DE CONTRASTECOLOREADO	
VENTAJAS	**LIMITACIONES**
Se puede emplear en equipos portátiles.	Suele ser inflamable.
No es necesaria la luz negra para su observación.	Las indicaciones son menos visibles que las obtenidas por penetrantes fluorescentes.
Puede emplearse en piezas en las que no está permitido el uso de agua para su lavado.	Difícil de aplicar en piezas rugosas, tales como piezas moldeadas en arena.
Puede utilizarse sobre piezas anodinadas.	
Es muy sensible para pequeñas discontinuidades.	

4.5.4 Etapas de inspección

Este Procedimiento constituye una guía para la inspección por líquidos penetrantes bajo una técnica para temperaturas estándar.

Para la aplicación de la técnica, la temperatura del penetrante y de la superficie a ser examinada, no debe estar por debajo de 10°C, ni por encima de 52°C durante el periodo de exanimación. Se permite el enfriamiento y calentamiento de la pieza para mantener la temperatura dentro del rango de 10°C a 52°C. (Este rango de temperatura se considera temperatura ambiente).

- **Limpieza y reparación previa de la superficie**

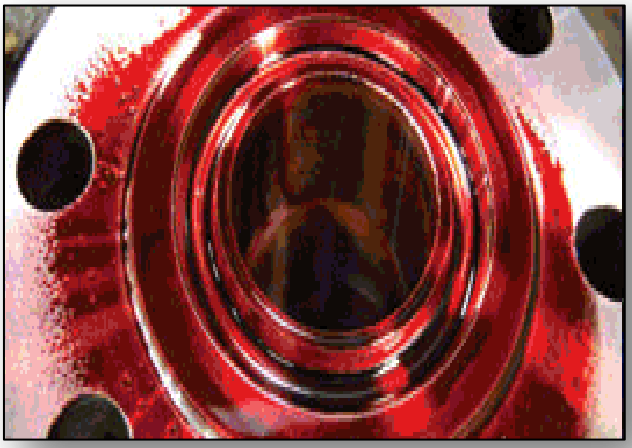
Antes de realizar el examen mediante Líquidos Penetrantes, la superficie a ser examinada y todas las áreas adyacentes, dentro de una distancia mínima de 25 mm, deberán estar secas y libres de suciedades, grasa, escamas, escorias de soldadura y otros materiales extraños que puedan encubrir las aberturas superficiales o interferir de algún modo con el examen.

Para realizar la limpieza, se usará grata manual o eléctrica para remover cualquier irregularidad superficial que pueda enmascarar las indicaciones de discontinuidades inaceptables. Además se empleará cualquier tipo de removedor comercial que cumpla con los requisitos de T-625, Sección V del Código ASME.

Después de la limpieza, se permitirá el secado de todas las superficies a ser examinadas por evaporación normal.

- **Aplicación de líquido penetrante sobre la superficie de muestra**

Foto 5. Aplicación del líquido penetrante coloreado.



Se hará la aplicación del líquido penetrante por proyección del líquido sobre la superficie y a una distancia no mayor de 8” o la que recomiende el fabricante.

Esta operación debe durar determinado tiempo de manera que el líquido penetre completamente en las discontinuidades que pudieran existir. Ver tabla 3 y 4.

Tabla 3. Tiempo de penetración (Liquido penetrante fluorescente) en algunos materiales.

NATURALEZA DEL MATERIAL	ESTADO O PROCESO	TIPO DE DISCONTINUIDAD	TIEMPO DE PENETRACIÓN EN MINUTOS	
			PENETRANTE AUTOEMULSONIABLE	PENETRANTE POSTEMULSIONABLE
Aluminio	Moldeado	Porosidad	5 - 15	5
	Forjado	Fragilidad en frío	5 - 15	5
	Soldadura	Pliegues	N/R	10

	Todos los estados	Falta de fusión, grietas	30	5
Magnesio	Moldeado	Moldeado	15	5
	Forjado	Forjado	15	5
	Soldadura	Soldadura	N/R	10
	Todos los estados	Todos los estados	30	10
Acero	Moldeado	Moldeado	30	10
	Forjado	Forjado	30	10
	Soldadura	Soldadura	N/R	10
	Todos los estados	Todos los estados	60	20

Tabla 4. Tiempo de penetración (Liquido penetrante coloreado) para algunos materiales.

NATURALEZA DEL MATERIAL	ESTADO O PROCESO	TIPO DE DISCONTINUIDAD	TIEMPO DE PENETRACIÓN EN MINUTOS
			PENETRANTE COLOREADO POSTEMULSIONABLE
Aluminio	Moldeado	Porosidad	3 – 5
	Forjado	Fragilidad en frió	3 - 5
	Soldadura	Pliegues	8 - 10
	Todos los estados	Falta de fusión, grietas	3 - 5
Magnesio	Moldeado	Moldeado	3 - 5
	Forjado	Forjado	3 - 5
	Soldadura	Soldadura	8 - 10
	Todos los estados	Todos los estados	8 - 10
Acero	Moldeado	Moldeado	8 - 10
	Forjado	Forjado	8 - 10
	Soldadura	Soldadura	8 - 10

	Todos los estados	Todos los estados	18 - 20

El tiempo de emulsificación solo se toma en cuenta en los penetrantes postemulsificables, variando según el estado de la superficie liso o rugoso.

En general, los tiempos de emulsificación varían entre 10 segundos o incluso menos, hasta 5 minutos, pero solo se hará una mayor aproximación a la vista del problema concreto y de los medios disponibles.

- **Remoción del exceso de líquido penetrante**

Tiene por objeto dejar libre la superficie del material del líquido que no ha penetrado en las discontinuidades. Se llevara a cabo de diversas formas según el carácter del líquido penetrante. Pudiendo utilizarse agua o disolventes especiales.

El exceso de penetrante puede ser removido usando un material absorbente limpio (trapo o papel que no deje hilachas) humedecido en agua.

- **Aplicación del revelador**

El revelador actúa como extractor del penetrante retenido en las discontinuidades, haciéndolas visibles, polvo muy fino, normalmente blanco o débilmente coloreado que se aplicara directamente en seco o bien por vía húmeda como suspensión en un líquido volátil.

El tiempo de revelado suele ser del orden de los 30 segundos a 1 minuto, sobre todo cuando se trata de reveladores aplicados en forma de polvo seco o en suspensión en líquidos volátiles.

El tiempo para que aparezca la indicación es inversamente proporcional al volumen de la discontinuidad. Las discontinuidades grandes aparecen rápidamente. Mientras que habrá que dejar actuar el revelador un cierto tiempo para que vayan apareciendo las más pequeñas.

La superficie examinada deber ser observada de cerca durante la aplicación del revelador para monitorear el comportamiento de indicaciones que tienden a sangrar profusamente. La interpretación final debe ser hecha después que el penetrante ha sangrado 7 a 30 minutos.

Foto 6. Resultados de los líquidos penetrantes coloreados.

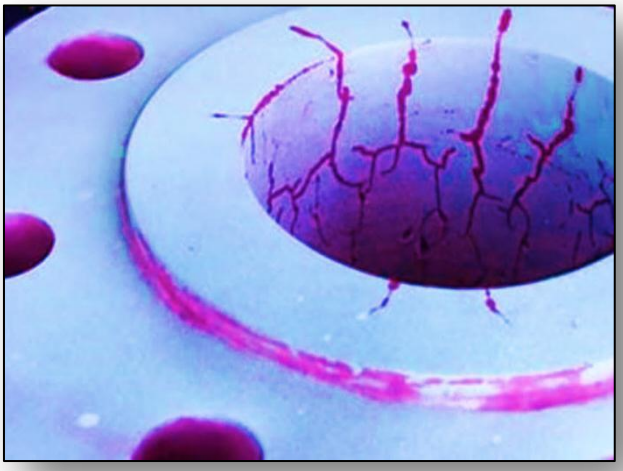
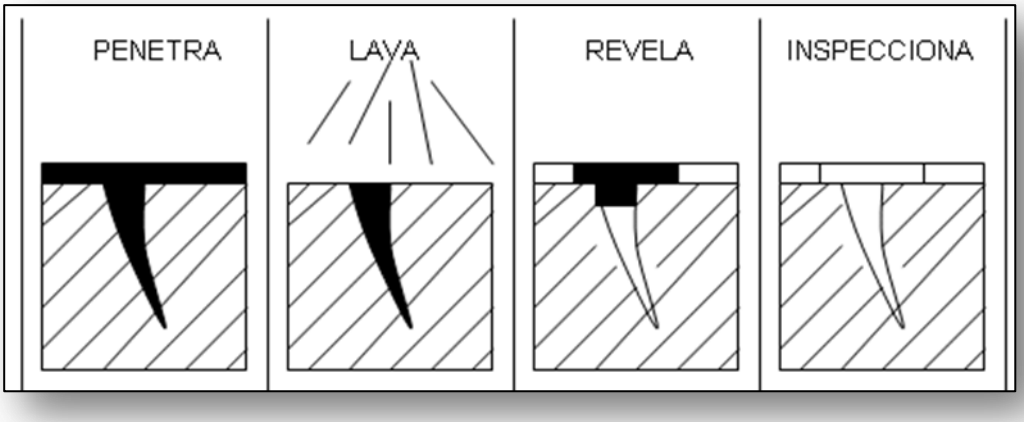


Foto 7. Resultados líquidos fluorescentes.

Figura 3. Etapas de inspección.



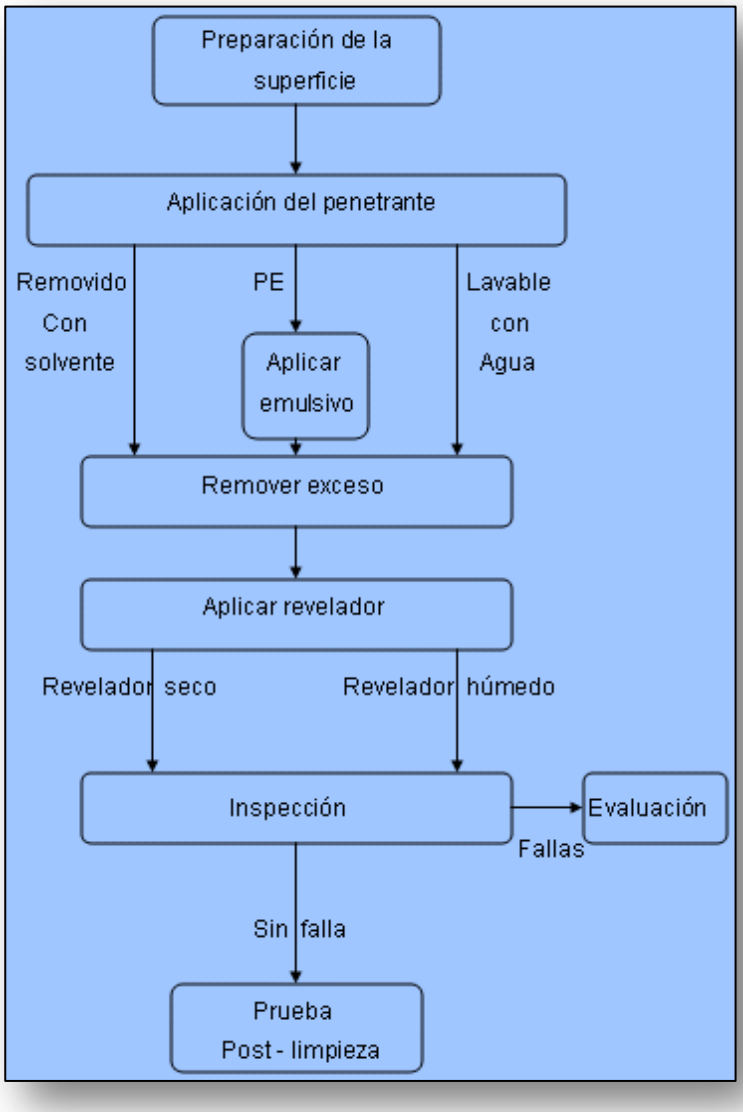
- **Limpieza final**

La limpieza final deberá llevarse a cabo en razón de que los productos usados en el ensayo pueden interferir con los procesos siguientes o tener un efecto nocivo

para las piezas en servicio.

Los productos utilizados en el proceso con líquidos penetrantes pueden reaccionar con los materiales de la pieza en servicio y producir corrosión. Cualquiera de los métodos usados en la limpieza previa puede ser empleado en la limpieza final.

Figura 4. Diagrama general de los líquidos penetrantes.



4.5.5 Evaluación

- **Penetrantes visibles**

Para la interpretación de los resultados, se puede utilizar luz artificial o luz natural, se deben analizar los resultados a plena luz del día o en caso contrario, se debe proveer una linterna de luz blanca o amarilla en buenas condiciones de funcionamiento.

- **Penetrantes fluorescentes**

Se debe realizar en una zona oscura. La luz negra debe dejarse calentar al menos 5 minutos. El inspector deberá estar en el área como mínimo un minuto antes de realizar la inspección

La luz negra deberá tener una intensidad de 1000 $\frac{\mu W}{cm^2}$.

- **Indicaciones relevantes**

Verdaderas indicaciones de penetrante en la superficie de la pieza que indiquen al inspector que algún tipo de discontinuidad está presente y que con toda probabilidad constituye un defecto.

- **Indicaciones no relevantes**

Tipo de indicaciones que suelen ser causadas por discontinuidades superficiales, cuya presencia no está asociada a imperfecciones de la pieza sino a factores geométricos o de diseño.

- **Indicaciones falsas**

Evitar la presencia de penetrante en la superficie de la pieza, producida generalmente por una mala remoción del mismo durante el proceso de lavado o por contaminación de la superficie.

Se debe evitar el contacto del penetrante con las manos del operador, revelador contaminado, contaminación de la superficie de la pieza por contacto con otra pieza, o manchas de penetrante en la mesa de inspección.

4.5.6 Criterios de aceptación

Las indicaciones que sean relevantes, deben ser evaluadas en función de los criterios de aceptación o rechazo que fije la norma bajo la cual se calificaran los defectos encontrados indicados.

Algunas de estas normas son:

- ASME SECCION VIII DIVISION 1 VER APENDICE 8 (8 - 4).
- API 1104 Sección 6.
- AWS D.1.1 Sección 6. Parte C 6.10
- API 650 WELDED STEEL TANKS FOR OIL STORAGE.[5]

[5] Referencia tomada de: Inspección con líquidos penetrantes. De la página 34 a la 46. Recuperado el (08 de Mayo de 2014) disponible en: http://www.comtecol.com/intranet/manual/docu/PROCEDIMIENTO%20DE%20INSPECCION%20DE%20SOLDADURA%20LP.pdf

4.6 MÉTODOS PARA REALIZAR Y APLICAR EL ENSAYO DE PARTICULAS MAGNÉTICAS

4.6.1 Normas de referencia

- Código ASME Sección V, Artículos 7.
- ANSI / ASTM E-1444. Práctica Recomendada para el Examen por Partículas Magnéticas.
- ASNT SNT-TC-1A - Recommended Practice for Personal Qualification and Certification in Nondestructive Testing.

4.6.2 Inspección con partículas magnéticas

El ensayo de Partículas Magnéticas es uno de los más antiguos que se conoce, encontrando en la actualidad, una gran variedad de aplicaciones en las diferentes industrias. Es aplicable únicamente para inspección de materiales con propiedades ferromagnéticas, ya que se utiliza fundamentalmente el flujo magnético dentro de la pieza, para la detección de discontinuidades.

Mediante este ensayo se puede lograr la detección de defectos superficiales y sub-superficiales (hasta 3 mm debajo de la superficie del material). El acondicionamiento previo de la superficie, al igual que en las Tintas Penetrantes, es muy importante, aunque no tan exigente y riguroso.

La aplicación del ensayo de Partículas Magnéticas consiste básicamente en magnetizar la pieza a inspeccionar, aplicar las partículas magnéticas (polvo fino de

limaduras de hierro) y evaluar las indicaciones producidas por la agrupación de las partículas en ciertos puntos. Este proceso varía según los materiales que se usen, los defectos a buscar y las condiciones físicas del objeto de inspección.

Para la magnetización se puede utilizar un banco estacionario, un yugo electromagnético, electrodos o un equipo portátil de bobina flexible, entre otros. Se utilizan los diferentes tipos de corrientes (alterna, directa, semi-rectificada, entre otros), según las necesidades de cada inspección. El uso de imanes permanentes ha ido desapareciendo, ya que en éstos no es posible controlar la fuerza del campo y son muy difíciles de manipular.

Para realizar la inspección por Partículas Magnéticas existen varios tipos de materiales que se pueden seleccionar según la sensibilidad deseada, las condiciones ambientales y los defectos que se quieren encontrar. Las partículas magnéticas pueden ser:

- **Secas**

Fluorescentes y visibles (varios colores).

- **Húmedas**

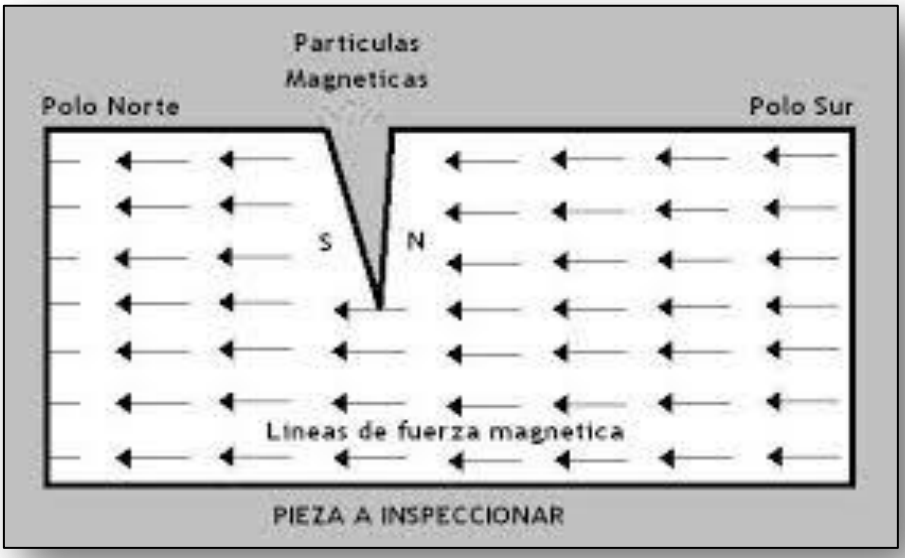
Fluorescentes y visibles (varios colores).
Los métodos de magnetización y los materiales se combinan de diferentes maneras según los resultados deseados en cada prueba y la geometría del objeto a inspeccionar.

4.6.3 Principios Básicos

Cuando se estudia el comportamiento de un imán permanente, se puede observar que éste se compone por dos polos, Norte y Sur, los cuales determinan la dirección de las líneas de flujo magnético que viajan a través de él y por el espacio que lo rodea, siendo cada vez más débiles con la distancia.

Si cortamos el imán en dos partes, observaremos que se crean dos imanes nuevos, cada uno con sus dos polos, Norte y Sur, y sus correspondientes líneas de flujo magnético. Esta característica de los imanes es la que permite encontrar las fisuras abiertas a la superficie, y los defectos internos en una pieza, como se explicará a continuación.

Figura 5. Flujo del campo magnético.



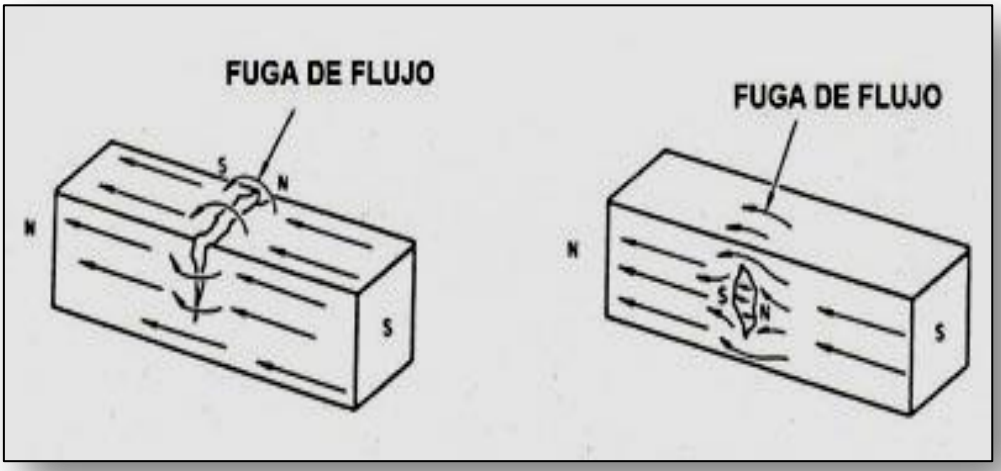
La magnetización de un material ferromagnético se puede lograr mediante la inducción de un campo magnético fuerte, desde una fuente externa de magnetización (un electroimán), o mediante el paso de corriente directamente a través de la pieza. La fuerza del campo generado es resultado de la cantidad de corriente eléctrica que se aplique y el tamaño de la pieza, entre otras variables.

Una vez magnetizado el objeto de estudio, éste se comporta como un imán, es decir, se crean en él dos polos magnéticos Sur y Norte. Estos polos determinan la dirección de las líneas de flujo magnético, las cuales viajan de Norte a Sur.

Teniendo la pieza magnetizada (magnetización residual), y/o bajo la presencia constante del campo magnético externo (magnetización continua), se aplica el polvo de limadura de hierro seco, o suspendido en un líquido (agua o algún destilado del petróleo). Donde se encuentre una perturbación o una fuga en las líneas de flujo magnético, las pequeñas partículas de hierro se acumularán, formando la indicación visible o fluorescente, dependiendo del material usado.

La perturbación o fuga del campo magnético se genera por la formación de dos polos pequeños N y S en los extremos del defecto (fisura, poro, inclusión no-metálica, entre otros). En la figura 6 se muestra este efecto.

Figura 6. Perturbación o fuga del campo magnético.



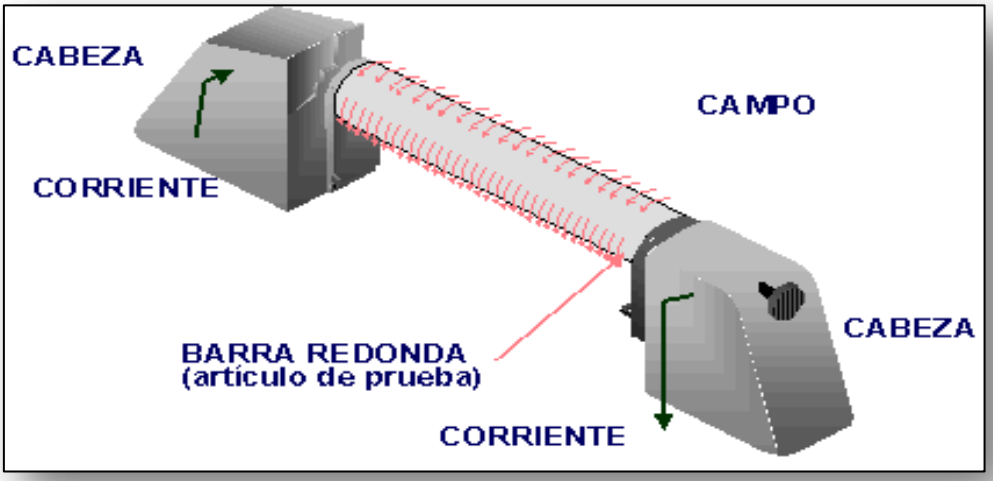
Al igual que en la mayoría de los Ensayos No Destructivos, en la inspección con Partículas Magnéticas intervienen muchas variables (corriente eléctrica, dirección del campo, tipo de materiales usados, etc.), las cuales deben ser correctamente manejadas por el inspector para obtener los mejores resultados. Por esta razón las normas MIL, ASTM, API, AWS y ASME entre muchas otras, y los manuales de mantenimiento de las aeronaves, exigen la calificación y certificación del personal que realiza este tipo de pruebas, con el fin de garantizar la confiabilidad de los resultados y así contribuir a la calidad del producto. Entre las regulaciones más conocidas de certificación de personal se encuentran: NAS-410, ISO 9712, SNT–TC–1A, ANSI/ASNT CP-189 y EN-473.[6]

Actualmente existen 32 variantes del método, que al igual que los líquidos penetrantes sirven para diferentes aplicaciones y niveles de sensibilidad. Algunas de ellas son:

[6] Referencia tomada de: Inspección con Partículas Magnéticas. De la página 47 a la 52. Recuperado el (08 de Mayo de 2014) disponible en: http://www.isotec.com.co/portal2/index.php?id=55.

- Magnetización por yugo.
- Magnetización por bobina.
- Magnetización con puntas de contacto.
- Magnetización entre cabezales.

Figura 7. Magnetización entre cabezales.



4.6.4 Etapas para la inspección

Las etapas básicas involucradas en la realización de una inspección por este método son:

- **Limpieza**

Todas las superficies a inspeccionar deben estar limpias y secas. La expresión “limpia” quiere decir que la superficie se encuentre libre de aceite, grasa, suciedad, arena, óxido, cascarilla suelta u otro material extraño, el cual pueda inferir con el ensayo.

- **Magnetización de la pieza**

Este paso puede efectuarse por medio de un imán permanente, con un electroimán o por el paso de una corriente eléctrica a través de la pieza. El tipo de magnetización a emplear depende del tipo de pieza, las Instalaciones existen en la empresa, el tipo de discontinuidad y la localización de la misma.

Foto 8. Magnetización de la pieza por medio de yugo y aplicación de las partículas coloreadas.

- **Corriente de magnetización**

Se seleccionará en función de la localización probable de las discontinuidades; si se desea detectar sólo discontinuidades superficiales, debe emplearse la corriente alterna, ya que ésta proporciona una mayor densidad de flujo en la superficie y por lo tanto mayor sensibilidad para la detección de discontinuidades superficiales; pero es ineficiente para la detección de discontinuidades sub-superficiales.

Si lo que se espera es encontrar defectos superficiales y sub-superficiales, es necesario emplear la corriente rectificada de media onda; ya que esta presenta una mayor penetración de flujo en la pieza.

- **Forma de Magnetizar**

La forma de magnetizar es también importante, ya que conforme a las normas comúnmente adoptadas, la magnetización con yugo sólo se permite para la detección de discontinuidades superficiales. Los yugos de AC o DC producen campos lineales entre sus polos y por este motivo tienen poca penetración. Otra técnica de magnetización lineal es emplear una bobina (solenoide). Si se selecciona esta técnica, es importante procurar que la pieza llene lo más posible el diámetro interior de la bobina; problema que se elimina al enredar el cable de magnetización alrededor de la pieza. Entre mayor número de vueltas (espiras) tenga un bobina, presentará un mayor poder de magnetización.

Cuando la pieza es de forma regular (cilíndrica), se puede emplear la técnica de cabezales, que produce magnetización circular y permite la detección de defectos paralelos al eje mayor de la pieza. Una variante de esta técnica es emplear contactos en los extremos de la pieza, que permiten obtener resultados similares.

Para la inspección de piezas con alta permeabilidad y baja retentividad, como es el caso de los aceros al carbono o sin tratamiento térmico de endurecimiento, es recomendada la técnica de magnetización continua, siendo el campo magnético más intenso y permite que las partículas sean atraídas hacia cualquier distorsión o fuga de campo, para así indicar la presencia de una posible discontinuidad.

- **Observación e interpretación de los resultados**

La inspección visual de las indicaciones se efectuará en parte durante la magnetización y continuará el tiempo necesario después de que el medio de examen se haya estabilizado, para explorar toda la zona de ensayo. Las discontinuidades quedarán indicadas por la retención de las partículas magnéticas. Con base en lo anterior, se puede determinar la existencia de discontinuidades así como su forma, tamaño y localización.

Foto 9. Falta de fusión, método partículas secas coloreadas.

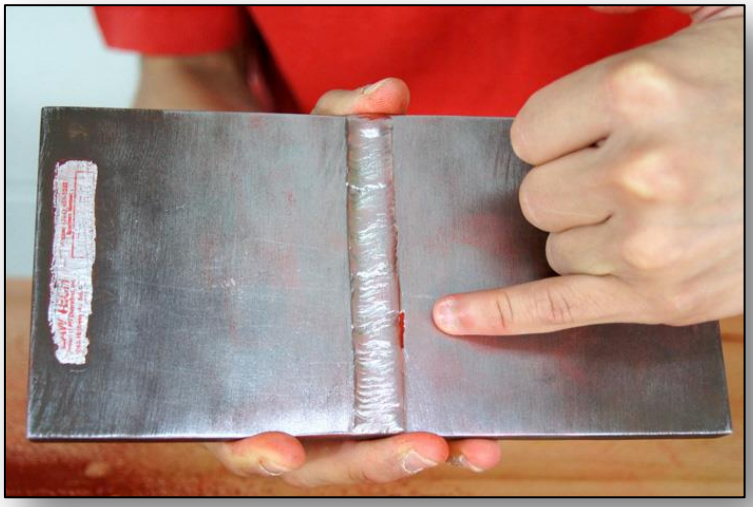
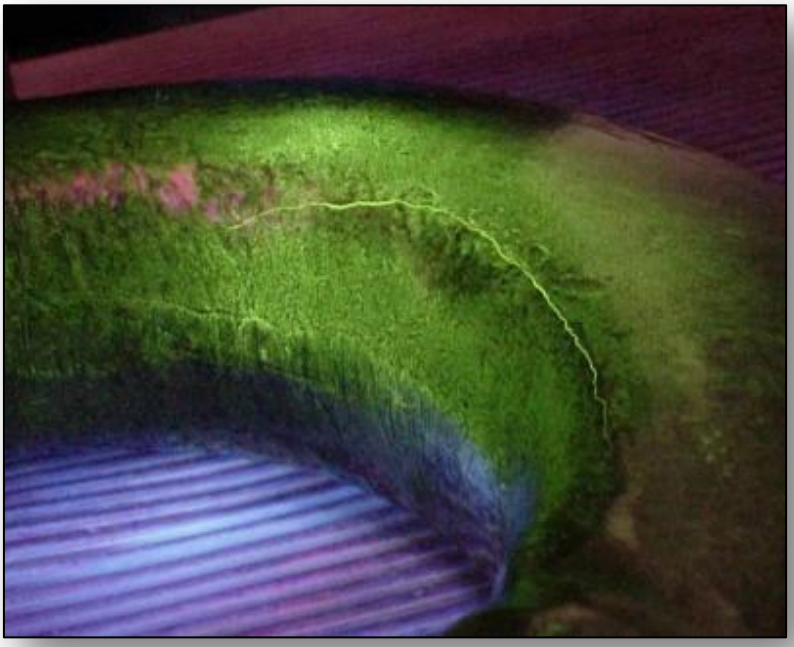


Foto 10. Grieta encontrada en pieza, método partículas húmedas fluorescentes.



- **Desmagnetización**

Debido a que algunos materiales presentan magnetismo residual, en ocasiones es necesario efectuar la desmagnetización de la pieza para evitar que el magnetismo residual afecte el funcionamiento o el procesamiento posterior de la misma. Como regla general se recomienda que si se emplea corriente alterna, se desmagnetice con corriente alterna; de manera similar, si se magnetiza con corriente rectificada, se debe desmagnetizar con corriente rectificada.

La desmagnetización consiste en aplicar un campo magnético que se va reduciendo de intensidad y cambiando de dirección hasta que el magnetismo residual en el material queda dentro de los límites permisibles.[7]

[7] Referencia tomada de: Inspección con Partículas Magnéticas. De la página 53 a la 57. Recuperado el (12 de Mayo de 2014) disponible en: http://www.sistendca.com/DOCUMENTOS/Manual%20Introduccion%20a%20los%20END.pdf.

5 PROCEDIMIENTO

La realización del banco móvil consiste en adecuar una herramienta para realizar los ensayos de partículas magnéticas y líquidos penetrantes en los laboratorios de la Institución. Este banco móvil se fabricó en una forma de cubículo para garantizar que cuando se hagan las partículas magnéticas y líquidos penetrantes fluorescentes haya hermeticidad a la luz.

Para su fabricación se utilizaron los siguientes materiales:

- Tubería ϕ 1 ⅛" (pulgada).
- Lamina espesor $^1/_4$" (pulgada).
- 4 ruedas.
- Soldadura AWS E-6011.

En la fabricación se siguieron los siguientes pasos:

- Adquisición de los materiales.
- Corte de la tubería según necesidad.
- Armazón y aplicación de la soldadura a la parte estructural.
- Instalación de láminas para su cubierta y fabricación de la puerta de acceso.
- Instalación de mesón para realizar los ensayos.
- Instalación de ruedas e cada esquina.

NOTA: Ver plano de fabricación.

6 CRONOGRAMA DE ACTIVIDADES

	ACTIVIDADES	MES															
		FEBRERO				MARZO				ABRIL				MAYO			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Recolección de información.																
2	Asistencia a asesorías.																
3	Realización del informe escrito.																
4	Diseño de Banco Móvil en software.																
5	Diseño de planos.																
6	Fabricación del Banco Móvil.																
7	Informes.																

7 CONCLUSIONES

Los ensayos nos destructivos permiten conocer con anterioridad a que una pieza falle, los posibles defectos e imperfecciones presentes.

La importancia y gran ventaja de los ensayos no destructivos es que permiten realizar las pruebas sin deteriorar ni maltratar la pieza y arrojando información valiosa de su estado.

Dentro de la soldadura se practican mucho este tipo de pruebas, ya que permiten evaluar de manera muy precisa los acabados superficiales y sub-superficiales y encontrar los defectos en el procedimiento.[8]

Los ensayos no destructivos requieren personal calificado y con experiencia, pues no es posible realizar estas pruebas únicamente teniendo disponibilidad de los equipos.

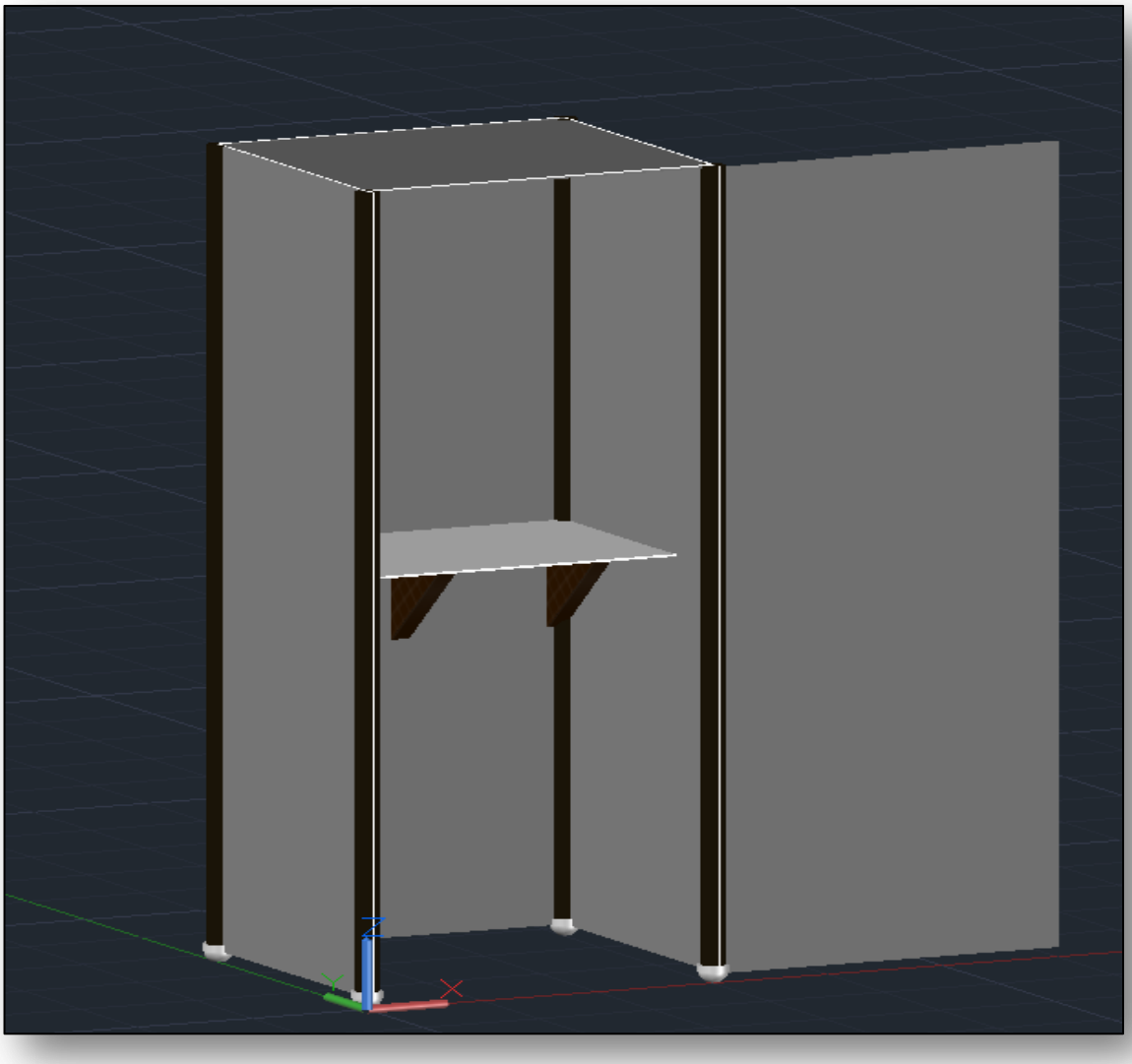
Al finalizar este proyecto podemos concluir que contamos con todo lo necesario para la realización de los ensayos de líquidos penetrantes y partículas magnéticas en el área de ensayos no destructivos de la Institución.

Este proyecto nos ayudó a reafirmar nuestros conocimientos y a sentirnos seguros con la información que tenemos en nuestras manos. Esperamos que este proyecto sirva de referencia a futuros estudiantes de la carrera.

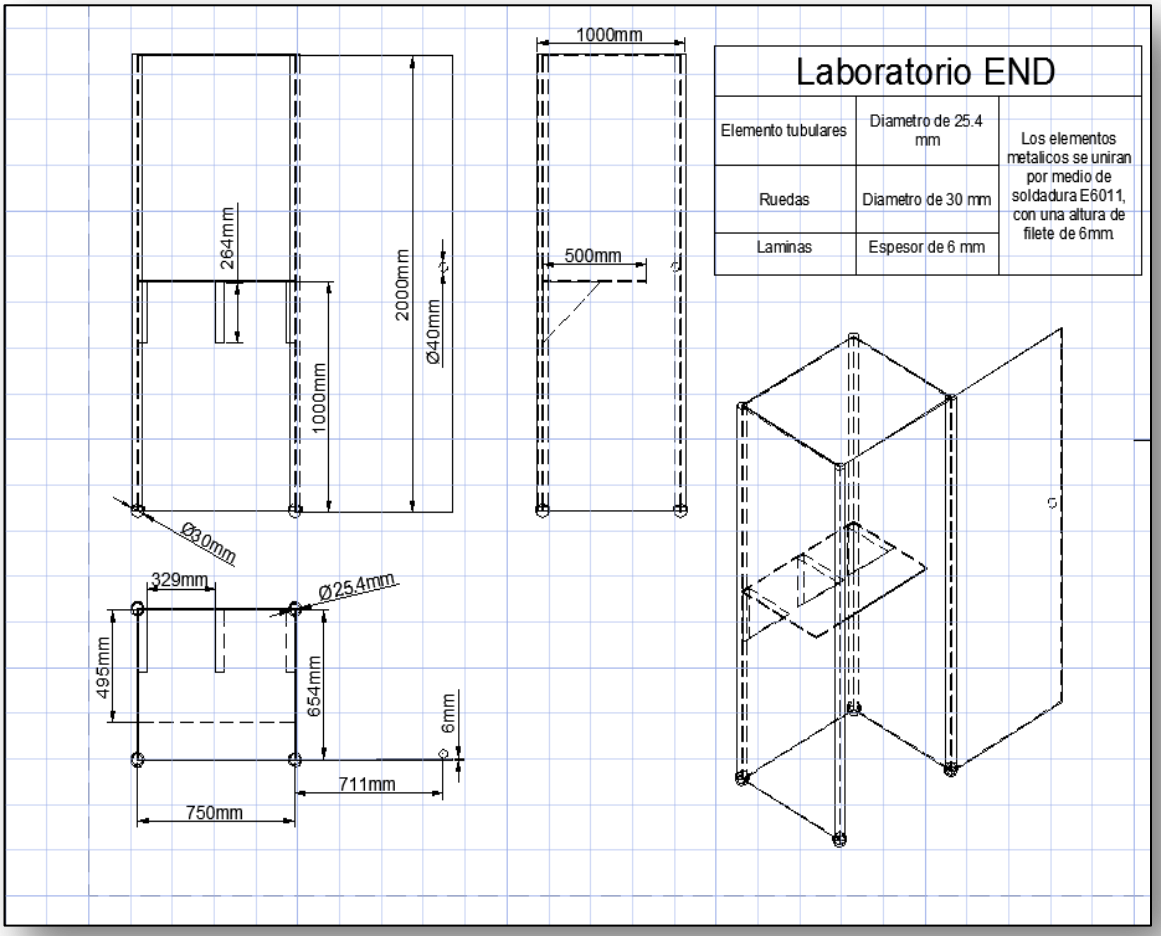
[8] Referencia tomada de: FERNANDEZ, Alonso. Ensayos no destructivos por líquidos penetrantes y partículas magnéticas. España : Instituto de Fomento regional, 1998. Recuperado el (18 de Mayo de 2014) disponible en: http://juankasandoval.wikispaces.com/file/view/Trab.+NTICS+1.pdf.

8 PLANOS

Plano 1. Isométrico del banco móvil.

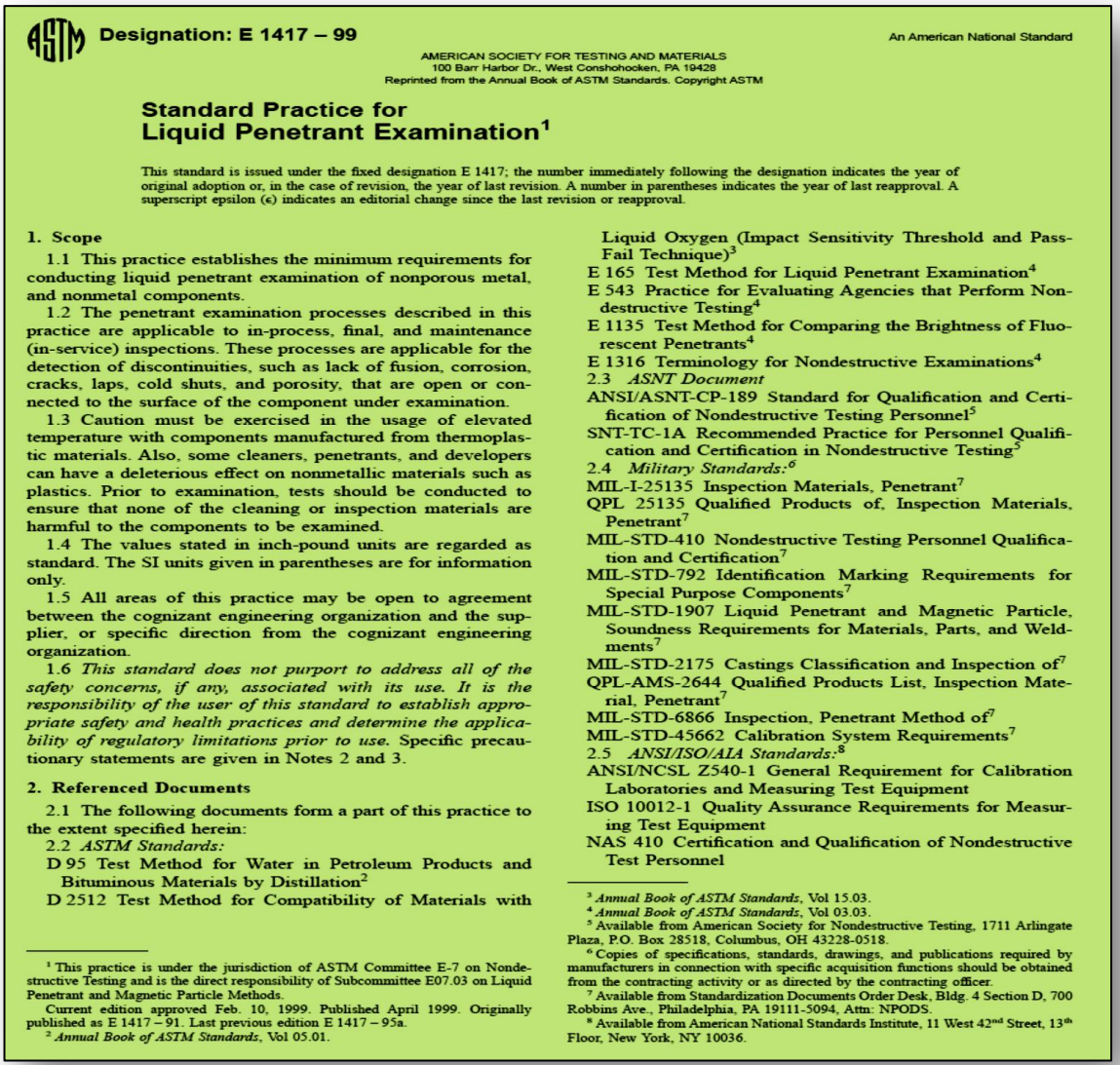


Plano 2. Vistas generales del banco móvil.



9 ANEXOS

Anexo 1. Norma ASTM E 1417. Práctica Recomendada para el Examen por Líquidos Penetrantes.



Designation: E 1417 – 99

An American National Standard

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428
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Standard Practice for Liquid Penetrant Examination[1]

This standard is issued under the fixed designation E 1417; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice establishes the minimum requirements for conducting liquid penetrant examination of nonporous metal, and nonmetal components.

1.2 The penetrant examination processes described in this practice are applicable to in-process, final, and maintenance (in-service) inspections. These processes are applicable for the detection of discontinuities, such as lack of fusion, corrosion, cracks, laps, cold shuts, and porosity, that are open or connected to the surface of the component under examination.

1.3 Caution must be exercised in the usage of elevated temperature with components manufactured from thermoplastic materials. Also, some cleaners, penetrants, and developers can have a deleterious effect on nonmetallic materials such as plastics. Prior to examination, tests should be conducted to ensure that none of the cleaning or inspection materials are harmful to the components to be examined.

1.4 The values stated in inch-pound units are regarded as standard. The SI units given in parentheses are for information only.

1.5 All areas of this practice may be open to agreement between the cognizant engineering organization and the supplier, or specific direction from the cognizant engineering organization.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Notes 2 and 3.

2. Referenced Documents

2.1 The following documents form a part of this practice to the extent specified herein:

2.2 *ASTM Standards:*

D 95 Test Method for Water in Petroleum Products and Bituminous Materials by Distillation[2]

D 2512 Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Technique)[3]

E 165 Test Method for Liquid Penetrant Examination[4]

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[4]

E 1135 Test Method for Comparing the Brightness of Fluorescent Penetrants[4]

E 1316 Terminology for Nondestructive Examinations[4]

2.3 *ASNT Document*

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[5]

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing[5]

2.4 *Military Standards:*[6]

MIL-I-25135 Inspection Materials, Penetrant[7]

QPL 25135 Qualified Products of, Inspection Materials, Penetrant[7]

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[7]

MIL-STD-792 Identification Marking Requirements for Special Purpose Components[7]

MIL-STD-1907 Liquid Penetrant and Magnetic Particle, Soundness Requirements for Materials, Parts, and Weldments[7]

MIL-STD-2175 Castings Classification and Inspection of[7]

QPL-AMS-2644 Qualified Products List, Inspection Material, Penetrant[7]

MIL-STD-6866 Inspection, Penetrant Method of[7]

MIL-STD-45662 Calibration System Requirements[7]

2.5 *ANSI/ISO/AIA Standards:*[8]

ANSI/NCSL Z540-1 General Requirement for Calibration Laboratories and Measuring Test Equipment

ISO 10012-1 Quality Assurance Requirements for Measuring Test Equipment

NAS 410 Certification and Qualification of Nondestructive Test Personnel

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[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.03 on Liquid Penetrant and Magnetic Particle Methods.

Current edition approved Feb. 10, 1999. Published April 1999. Originally published as E 1417 – 91. Last previous edition E 1417 – 95a.

[2] *Annual Book of ASTM Standards*, Vol 05.01.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[6] Copies of specifications, standards, drawings, and publications required by manufacturers in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.

[7] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[8] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

2.6 *SAE Standard:*[9]

AMS 2644 Inspection Material, Penetrant

2.7 *DoD Contracts*—Unless otherwise specified, the issues of the documents that are DoD adopted are those listed in the issue of the DoDISS (Department of Defense Index of Specifications and Standards) cited in the solicitation.

2.8 *Order of Precedence*—In the event of conflict between the text of this practice and the references cited herein, the text of this practice takes precedence.

3. Terminology

3.1 *Definitions:*

3.1.1 The terminology relating to liquid penetrant examination that appears in Terminology E 1316 shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aerospace*—any component that will be installed on a system that flies.

3.2.2 *cognizant engineering organization*—the company, agency, or other authority responsible for the design or after delivery, end use of the system or component for which liquid penetrant examination is required; in addition to design personnel, this may include personnel from material, and process engineering, stress analysis, NDT or quality groups and others, as appropriate.

3.2.3 *component*—the part(s) or element(s) of a system described, assembled, or processed to the extent specified by the drawing.

3.2.4 *final examination*—the final examination performed for the acceptance of the item. Any change to the item's surface such as machining, grinding, welding, heat treatment, or etching by subsequent manufacturing operation, may render the previous examination invalid, requiring reexamination of all affected surfaces, unless otherwise approved in the contract.

3.2.5 *in-process*—that which occurs during manufacturing before a component is in final form.

3.2.6 *in-service*—refers to components that are in use or storage for their intended function.

3.2.7 *linear indication*—penetrant indications with at least a three to one length to width ratio.

3.2.8 *reprocess*—repeat, after cleaning, the application and appropriate processing of penetrant, emulsifier (as required), and developer (as required).

3.2.9 *rounded indication*—penetrant indication whose length to width ratio is less than three-to-one.

3.2.10 *supplier*—the organization contracted to supply the material, parts, or assembly.

3.2.11 *turbine engine critical components*—any component on turbine engine designated by the manufacturer as "critical."

4. Significance and Use

4.1 This practice establishes the basic parameters for controlling the application of the liquid penetrant method. This practice is written so it can be specified on the engineering drawing, specification, or contract. It is not a detailed how-to procedure to be used by the inspector and, therefore, must be supplemented by a detailed procedure that conforms to the requirements of this practice. Test Method E 165 contains information to help develop detailed how-to requirements.

5. Classification

5.1 Penetrant examination processes and materials are classified in accordance with the material classification contained in MIL-I-25135 or AMS 2644. Penetrant systems covered by this practice shall be of the following types, methods, and sensitivity levels:

5.1.1 *Type*:

5.1.1.1 *Type I*—Fluorescent dye.

5.1.1.2 *Type II*—Visible dye.

5.1.2 *Method*:

5.1.2.1 *Method A*—Water washable.

5.1.2.2 *Method B*—Post-emulsifiable, lipophilic.

5.1.2.3 *Method C*—Solvent-removable.

5.1.2.4 *Method D*—Post-emulsifiable, hydrophilic.

5.1.3 *Sensitivity*—(These levels apply to Type I penetrant systems only. Type II penetrant systems have only a single sensitivity and it is not represented by any of the levels listed as follows):

5.1.3.1 *Sensitivity Level ½*—Very low.

5.1.3.2 *Sensitivity Level 1*—Low.

5.1.3.3 *Sensitivity Level 2*—Medium.

5.1.3.4 *Sensitivity Level 3*—High.

5.1.3.5 *Sensitivity Level 4*—Ultrahigh.

5.2 Developers shall be of the following forms:

5.2.1 *Form a*—Dry powder.

5.2.2 *Form b*—Water-soluble.

5.2.3 *Form c*—Water-suspendable.

5.2.4 *Form d*—Nonaqueous for Type I fluorescent penetrant.

5.2.5 *Form e*—Nonaqueous for Type II visible dye.

5.2.6 *Form f*——Specific application.

5.3 Solvent removers shall be of the following classes:

5.3.1 *Class 1*—Halogenated.

5.3.2 *Class 2*—Nonhalogenated.

5.3.3 *Class 3*—Specific application.

6. General Practices

6.1 *Responsibility for Examination*—Unless otherwise specified in the contract or purchase order, the cognizant engineering organization is responsible for the performance of all examination requirements as specified herein. The cognizant engineering organization shall specify more stringent requirements than the minimum specified in this practice when necessary to ensure that a component meets its functional and reliability requirements. Except as otherwise specified, the supplier may utilize his own facilities or any other facilities suitable for the performance of the examination requirements specified herein. The purchaser reserves the right to perform any of the examinations set forth in this practice where such examinations are deemed necessary to ensure that supplies and services conform to prescribed requirements.

[9] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

6.2 *Specifying*—When examination is required in accordance with this practice the orders, contracts, or other appropriate documents shall specify the criteria by which the acceptability of components is to be evaluated. An example of such criteria is in MIL-STD-1907; however, other criteria may be utilized. Engineering drawings or other applicable documents shall indicate the acceptance criteria for the entire component; zoning may be used. Examination on a sampling basis shall not be allowed unless specifically permitted by the contract.

6.3 *Personnel Qualification*—Personnel performing examinations to this practice shall be qualified and certified in accordance with ASNT Personnel Qualification SNT-TC-1A, ANSI/ASNT CP-189, NAS 410, or MIL-STD-410 for military purposes, or as specified in the contract or purchase order.

6.4 *Agency Qualification*—The agency performing this practice may be evaluated in accordance with Practice E 543.

6.5 *Materials*:

6.5.1 *Qualified Materials*—Only materials listed or approved for listing on QPL-25135 or QPL-AMS 2644 (reference MIL-I-25135 or AMS 2644) shall be utilized for penetrant examination. Materials not conforming to the requirements of MIL-I-25135 or AMS 2644 may be used only when a waiver is obtained from the cognizant engineering organization.

6.5.2 *Liquid Oxygen (LOX) Compatible Materials*—Penetrant materials tested in accordance with Test Method D 2512 and passing at 70 ft·lbf (95 J) or higher, shall be used on LOX wetted surfaces that cannot be thoroughly postcleaned. Use of these materials shall be in accordance with the material supplier instructions and shall require approval of the cognizant engineering organization when such materials do not meet the requirements of MIL-I-25135 or AMS-2644.

6.6 *Equipment and Facilities*—Processing equipment used in the penetrant examination process shall be constructed and arranged to permit a uniform and controlled operation. The equipment shall meet all applicable national and local safety requirements as well as the requirements specified herein.

6.6.1 *Viewing Areas*—Areas where parts are reviewed shall be kept clean at all times. For visible dye examination, Type II, the lighting system shall provide at least 100 fc (1000 lx) of visible light when measured at the examination surface. For stationary fluorescent dye examination, Type I, the ambient visible light background shall not exceed 2 fc (20 lx) at the examination surface. The black lights shall provide a minimum of 1000 $\mu W/cm^2$ at the examination surface. Black lights shall meet the requirements of 7.8.5.1. Viewing areas for portable fluorescent dye examination shall utilize dark canvas, photographer's black cloth, or other methods to reduce the visible light background to the lowest possible level during examination and black light intensity shall meet the above requirements.

6.6.2 *Drying Oven*—When components are oven dried, the dryer must be a forced-air recirculating type. In automated systems, where parts are dried by radiant heat and forced air, the travel speed of the system shall be such as to preclude overdrying of parts. The forced air does not have to be recirculating but must preclude contamination of the parts. The temperature shall be controlled with a calibrated device capable of maintaining the oven temperature at ±15°F of the temperature for which it is set. The oven shall not exceed 160°F (71°C). The temperature indicator shall be accurate to ±10°F of the actual oven temperature.

6.7 *Written Procedures*—All liquid penetrant examination procedures are similar for many components, a master written procedure may be utilized that covers the details common to a variety of components. As a minimum, the following information is required either in individual procedures, or a master procedure, or a combination thereof:

6.7.1 Details of the precleaning and etching process, including the materials used and specification or other document controlling the examination process, the drying parameters and the processing times. If these operations are performed by other than examination personnel, details concerning the operations may be specified in other documents but must be referenced in the procedure(s). Reference Test Method E 165 for detailed cleaning methods and instructions.

6.7.2 Classification of the penetrant examination materials required in accordance with Section 5 and MIL-I-25135 or AMS-2644.

6.7.3 Complete processing parameters for the penetrant examination materials including concentrations, application methods, dwell times, drying times, temperatures, and controls to prevent excessive drying of penetrant or overheating of component, as appropriate. Reference Test Method E 165 for additional details.

6.7.4 Complete examination/evaluation requirements including light intensities (both examination and ambient), the accept/reject criteria and the method and location of marking. Reference Test Method E 165 for additional details.

6.7.5 Identification of the components or areas within a component to be examined in accordance with the procedure.

6.7.6 Complete postcleaning procedures. If postcleaning is performed by other than examination personnel, details concerning this operation may be specified in other documents, but must be referenced in the procedure. Reference Test Method E 165 for additional details.

6.8 *Examination Sequence*—Final penetrant examination shall be performed after completion of all operations that could cause surface-connected discontinuities or operations that could expose discontinuities not previously open to the surface. Such operations include, but are not limited to, grinding, welding, straightening, machining, and heat treating.

6.8.1 *Surface Treatment*—Final penetrant examination may be performed prior to treatments that can smear the surface but not by themselves cause surface discontinuities. Such treatments include, but are not limited to, vapor blasting, deburring, sanding, buffing, sandblasting, lapping, or peening. Performance of final penetrant examination after such surface treatments requires that etching be included in the precleaning operation unless otherwise agreed on between the cognizant engineering organization and the NDT facility.

NOTE 1—Final penetrant examination should always precede peening.

6.8.2 *Surface Coatings*—All coatings and other surface conditions, such as, paint, plating, corrosion, etc. shall be removed from the area to be examined prior to penetrant examination. The penetrant examination shall precede any

surface finish, such as anodize, except for inservice parts that may be examined without removing the anodize.

6.9 *Material and Process Limitations*—Not all penetrant sensitivity levels, materials, and process methods are applicable to all examination requirements. The sensitivity level shall be adequate for the intended purpose of the examination. Unless there is an approval for deviation given by the cognizant engineering organization, the following selections are mandatory or forbidden, as indicated:

6.9.1 Forms *a* and *b* (dry powder and water soluble) developers shall not be used with Type II (visible dye) penetrant systems. This is not intended to prohibit the use of a Form *f* developer that has been qualified with a particular Type II system in accordance with MIL-I-25135 or AMS-2644.

6.9.2 Type II penetrant examination shall not be used for final acceptance examination of aerospace products. In addition, Type II penetrant examination shall not be used prior to a Type I penetrant examination of the same surface. This is not intended to eliminate the use of in-process Type II inspections where subsequent fabrication/forming operations remove the surfaces inspected.

6.9.3 The maintenance or overhaul examination of turbine engine critical components shall be done only with Type I, Methods C or D (solvent removable or post emulsified, hydrophilic) processes and either sensitivity Levels 3 or 4 penetrant materials.

6.10 *Records*—The results of all penetrant examinations shall be recorded. All recorded results shall be identified, filed, and made available to the cognizant engineering organization upon request. Records shall provide for traceability to the specific part or lot inspected. As a minimum the records shall include: a reference to the specific procedures used; location, classification, and disposition of relevant indications; the inspector's inspection stamp, electronic ID or signature; and the date of examination. Records shall be kept for a minimum of three years or as otherwise specified in the purchase order or contract.

7. Specific Practices (Fig. 1)

7.1 *Surface Preparation*—All surfaces to be examined shall be clean, dry, and free of soils, oil, grease, paint and other coatings (except as allowed by 6.8.2), corrosion products, scale, smeared metal, welding flux, chemical residues, or any other material that could prevent the penetrant from entering discontinuities, suppress dye performance, or produce unacceptable background. Cleaning methods, including etching, selected for a particular component shall be consistent with the contaminants to be removed and shall not be detrimental to the component or its intended function.

7.1.1 Solvent cleaning, that includes vapor degreasing, solvent soak, ultrasonic cleaning, or aqueous-based cleaning solutions shall be used for the removal of oils, greases, waxes and as the final cleaning step prior to penetrant examination unless etching is required.

7.1.2 Chemical cleaning shall be used for the removal of paints, varnishes, scale, carbon, or other contaminants that are not removable by solvent cleaning methods.

NOTE 2—**Precaution:** Caution should be exercised when using chemicals because they may irritate the eyes or skin.

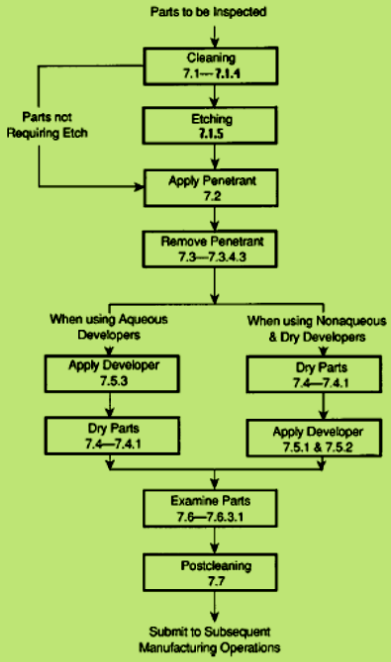

FIG. 1 Process Flow Chart

7.1.3 Mechanical cleaning shall be used for the removal of soils and other contaminants that cannot be removed by solvent or chemical cleaning methods.

7.1.4 Grit blasting without etching may be an acceptable cleaning method if it can be demonstrated that a sufficiently fine abrasive (150 grit or finer) will not cause peening and can be removed by a detergent or alkaline cleaner.

7.1.5 Etching, unless otherwise specified, shall be performed when evidence exists that previous cleaning, surface treatments, or service usage has produced a surface condition that degrades the effectiveness of penetrant examination. Etching processes shall be developed and controlled to prevent damage to the component under test. Etching is not required for those features such as close tolerance holes, close tolerance surfaces, faying surfaces, etc., where the function of the component or assembly would be degraded. Etching is not required for intermediate examination when the surface(s) are not retained in the final part/component configuration or when the final penetrant examination is preceded by etching.

7.2 *Penetrant Application*—Unless otherwise specified, the entire surface of the component shall be covered with penetrant. Large components may be examined in sections. Penetrant shall be applied by spraying, dipping, brushing, or other method to provide coverage as required. The component, penetrant, and ambient temperatures shall all be in the range from 40 to 125°F (4 to 52°C) unless otherwise specified.

7.2.1 *Penetrant Dwell Time*—The dwell time, unless otherwise specified, shall be a minimum of 10 min. For temperatures

between 40 and 50°F (4.4 and 10°C), dwell time shall be a minimum of 20 min. Rotate or otherwise move components, if required, during dwell to prevent pooling of the penetrant. For dwell times greater than 2 h, the penetrant shall be reapplied as required to prevent drying. The component shall be immersed in penetrant, if that is the application method, for no longer than half the total dwell time.

7.3 *Penetrant Removal*:

7.3.1 *Method A Process*—Water-washable penetrants shall be removed with a manual or automated water spray, or a manual wipe, or an air agitated immersion wash.

7.3.1.1 *Manual Spray*—Water pressure adequate to remove the penetrant shall be used but shall not exceed 40 psi (275 kPa). Water temperature shall be between 50 to 100°F (10 to 38°C). When hydro-air nozzles are used the air pressure shall not exceed 25 psi (172 kPa). A coarse spray shall be used with a minimum distance of 12 in. (30 cm), when possible between the spray nozzle and the part. Washing shall be conducted under appropriate illumination. Caution shall be exercised to ensure that over-washing does not occur. If over-washing occurs, the component(s) shall be thoroughly dried and reprocessed. After rinsing, drain water from the component and utilize repositioning, suction, blotting with clean absorbent materials, or filtered shop air at less than 25 psi (172 kPa) to prevent pooling in cavities, recesses, and pockets.

NOTE 3—**Caution:** Over-removal of the surface penetrant shall require that the component be cleaned and reprocessed. A good indicator of over-wash or over-removal of the surface penetrant is evidenced by the total lack of residue that may occur on all or a specific area of the part, see Test Method E 165.

7.3.1.2 *Automated Spray*—For automated spray systems, the wash parameters shall be such that the requirements of this practice are met. Water temperature shall be maintained between 50 to 100°F (10 to 38°C).

7.3.1.3 *Manual Wipe*—Excess penetrant shall be removed with a clean, dry, lint-free cloth or absorbent toweling. The remainder of the surface penetrant shall then be removed with a water-dampened cloth or towel. The surface shall not be flushed with water and the cloth or towel shall not be saturated with water. The component shall be examined under appropriate illumination to ensure adequate removal of the surface penetrant. The surface shall be dried by blotting with a clean, dry towel or cloth, or by evaporation.

7.3.1.4 *Immersion*—Immersion wash may be utilized if the water is air agitated and good circulation is maintained throughout the wash operation. Water temperature shall be maintained between 50 and 100°F (10 and 38°C).

7.3.2 *Method B Process*—Lipophilic post-emulsifiable penetrant shall be removed by air agitated water immersion or with a water spray or hydro-air spray rinse after application of an emulsifier and an appropriate emulsifier dwell time. Water pressure and temperature and air pressure shall meet the requirements specified for Method A.

7.3.2.1 Lipophilic emulsifiers shall be applied by immersion or flowing. Lipophilic emulsifiers shall not be applied by spray or brush and shall not be agitated while on the surface of the component. Maximum dwell times, unless otherwise specified, shall be 3 min for Type I systems and 30 s for Type II systems, or as recommended by the manufacturer. Actual dwell times shall be the minimum necessary to produce an acceptable background on the component.

7.3.2.2 *Rinsing*—After the appropriate emulsifier dwell time, emulsification shall be stopped by immersion or water spray. For spray removal of the penetrant/emulsifier mixture, the parameters of 7.3.1 apply. Dwell time in an agitated immersion rinse, if used, shall be the minimum required to remove the emulsified penetrant. Examine the components under appropriate illumination after rinsing. Clean and reprocess those components with excessive background. After rinsing, drain water from the component and utilize repositioning, suction, blotting with clean absorbent materials or filtered shop air at less than 25 psi (172 kPa) to prevent pooling. Caution shall be exercised to ensure that the air nozzle is held at a sufficient distance from the part to ensure that the developing indication is not smeared by the air blast. If over-emulsification is observed, the component must be cleaned and reprocessed.

7.3.3 *Method C Process*—Solvent-removable penetrants are removed by first wiping the excess penetrant with a clean, lint-free, dry cloth or absorbent toweling. The remainder of the surface penetrant is then removed with a solvent-dampened lint-free cloth or towel. The surface of the component shall not be flushed with solvent and the cloth or towel shall not be saturated with solvent. The component and cloth or toweling shall be observed under appropriate illumination to ensure adequate removal of the surface penetrant. Over-removal of the surface penetrant shall require the component to be cleaned and reprocessed. The surface shall be dried by blotting with a lint-free, dry cloth or towel, or by evaporation. Method C can also be used for water-washable penetrants using water or solvent for removal of excess penetrant.

7.3.4 *Method D Process*—Hydrophilic post emulsifiable penetrant shall be removed with a water prerinse, application of the hydrophilic emulsifier and then a postrinse.

7.3.4.1 *Rinse*—The water prerinse shall be applied for the minimum amount of time required to achieve removal of the bulk surface penetrant. The rinse parameters of 7.3.1 shall apply.

7.3.4.2 Hydrophilic emulsifier shall be applied by immersion, flowing, foaming, or spray. For immersion applications, the concentration, percent volume, shall be no higher than specified by the penetrant system supplier and shall not exceed that for which the system was qualified. For immersion applications, the emulsifier or part may be mildly agitated. Dwell time shall be the minimum required for adequate surface penetrant removal, but unless otherwise approved by the cognizant engineering organization, shall not exceed 2 min. For spray applications, the concentration shall not exceed 5 %.

7.3.4.3 *Postrinse*—After the application and dwell of the hydrophilic emulsifier, the component being examined shall be rinsed with water. The spray rinse parameters of 7.3.1 shall apply for the hydrophilic emulsifier. Evidence of over-removal shall require the part to be cleaned and reprocessed. Excessive background may be removed by additional (touchup) application of the hydrophilic emulsifier provided its maximum allowable dwell time is not exceeded. Additional rinsing of the

touch-up area will be required after application and dwell of the hydrophilic emulsifier. If careful touch-up application of the hydrophilic emulsifier does not produce an acceptable background, the part shall be cleaned and reprocessed. Manual systems shall require the use of appropriate illumination to ensure adequate penetrant removal.

7.4 *Drying*—The components shall be dried prior to the application of dry developer, nonaqueous developer, or examination without developer. The components should be drained of excess water but not dried before the application of aqueous soluble or suspendable developers. The components shall be dried after the application of aqueous developers.

7.4.1 *Drying Parameters*—Components shall be air dried at room temperature or in a drying oven. Oven temperatures shall not exceed that specified in 6.6.2. Drying time shall only be that necessary to adequately dry the part. Components shall be removed from the oven immediately after drying. Components shall not be placed in the oven with pooled water or pooled aqueous solutions/suspensions.

7.5 *Developing*—Unless otherwise specified, developers shall be utilized for penetrant examination. Type I penetrants that are qualified to MIL-I-25135 or AMS-2644 may be used without developer under either one of the following conditions: manufacturing examination of aluminum and magnesium castings classified by MIL-STD-2175 as Class 3 or 4, or with the expressed approval of the cognizant engineering organization. Minimum and maximum penetrant bleedout times without developer shall be 10 min and 2 h respectively. When developer is used, components that are not inspected before the maximum bleedout time shall be cleaned and reprocessed. When developer is not used, components that are not inspected before the maximum bleedout time shall be reprocessed.

7.5.1 *Dry Developers*—Components shall be dry before the developer is applied. Dry developer shall be applied in such a manner as to contact all surfaces to be inspected. Excess dry developer may be removed after the development time by light tapping or light air blow-off not exceeding 5 psi. Minimum and maximum developer dwell times shall be 10 min and 4 h, respectively. Dry developers shall not be used with Type II penetrants.

7.5.2 *Nonaqueous Developers*—Components, or areas requiring examination, shall be dry before application of the developer. Nonaqueous developer shall be applied by spraying. For Type I penetrants, the developer shall be applied as a uniform thin coating over the entire surface to be inspected. For Type II penetrants, the developer shall be applied over the entire surface to form a uniform, white coating to provide suitable color contrast for the penetrant indications. The uniformity and thickness of the developer coating is important for both types of penetrant systems. If the developer coating thickness is too heavy for Type I systems such that the metallic surface is completely masked, the component shall be cleaned and reprocessed. Unless otherwise specified, the minimum and maximum development times for nonaqueous developers are 10 min and 1 h respectively. For nonaqueous suspendable developer, the developer container shall be frequently agitated during application.

7.5.3 *Aqueous Developer*—Aqueous soluble developers shall not be used with Type II penetrants or Type I, Method A penetrants. Aqueous suspendable developers can be used with both Type I and Type II penetrants. Aqueous developers may be applied to the component after rinsing. Developers shall be applied by spray, flowing, or immersion. The applied developer shall not be allowed to puddle and shall completely cover all surfaces to be inspected. Components shall be air dried or oven dried to the requirements of 7.4.1. Minimum and maximum development times, after the component is dry, are 10 min and 2 h. Aqueous suspendable developers must be either constantly agitated to keep the particles from settling out of suspension or they must be thoroughly agitated prior to use to ensure that particles are in suspension.

7.6 *Inspection*—The inspection area shall meet the appropriate requirements of 7.8.5.3. Components shall be inspected before the maximum developing time, and if required by specific procedures, monitored periodically during the developing time. Components not inspected before the maximum developing time shall be cleaned and reprocessed.

7.6.1 *Type I Processes*—Inspector's vision shall be dark adapted for a minimum of 1 min prior to examining components. Longer times for more complete adaptation should be used if necessary. Inspectors shall not wear photochromic or permanently darkened lenses while processing or reviewing parts under black light. Black lights shall meet the requirements of 7.8.5.1. All areas of fluorescence shall be interpreted. Components with no indications or only nonrelevant indications shall be accepted. Components with relevant indications shall be evaluated with respect to the applicable acceptance criteria. Components with excessive background fluorescence shall be cleaned and reprocessed.

7.6.2 *Type II Processes*—All indications shall be interpreted. Components with no indications or only nonrelevant indications shall be accepted. Components with relevant indications shall be evaluated with respect to the applicable acceptance criteria. Components with excessive background shall be cleaned and reprocessed.

7.6.3 *Evaluation*—All indications found during inspection shall be evaluated in accordance with specified acceptance criteria.

7.6.3.1 *Indication Verification*—If allowed by the specific procedure, indications may be evaluated by wiping the indication with a solvent-dampened swab or brush, allowing the area to dry, and redeveloping. Redevelopment time shall be as long as the original development time, except nonaqueous redevelopment time shall be 3 min minimum. If no indication reappears, the original indication is considered false. This procedure may be performed twice for any given original indication.

7.6.3.2 *Discontinuity Removal*—When allowed by the specific examination procedure, discontinuity(ies) may be removed by an approved procedure such as sanding, either powered or manual, or grinding to determine the depth and extent of the discontinuity(ies). After the mechanical operation, the area shall be cleaned, etched (if permitted), and reexamined. The process used for reexamination shall be at least as sensitive as the original process.

7.6.4 *Sizing*—Either the indication or the discontinuity may be sized:

7.6.4.1 *Indication Sizing*—When sizing indications, the area shall be carefully evaluated under appropriate lighting after the required development time. Black and visible lights shall meet the requirements of 6.6.1.

7.6.4.2 *Discontinuity Sizing*—When sizing discontinuities, the area may be carefully wiped with solvent and the discontinuity measured using a scale and appropriate light that meets the requirements of 6.6.1. Discontinuities that are too small to be seen may be carefully wiped clean with solvent and the indication measured just as it is forming.

7.7 *Postcleaning*—Components shall be cleaned after examination to remove developers and other examination material residues if these are detrimental to subsequent operations or the components' intended function.

7.8 *Quality Control Provisions*—This section provides the controls necessary to ensure that the penetrant system materials and equipment provide an acceptable level of performance. The frequency of the required checks, as shown in Table 1 is based upon a facility operating in multi-shift operations daily. For facilities operating less frequently, the frequency of daily and weekly checks may be reduced, but must be performed prior to examinations. Other checks should be performed at the same frequency as for full-time operations. The NDT facility may perform these process control operations or contract for their performance with an independent laboratory.

7.8.1 *Material Conformance (New)*—Prior to being placed in use, the conformance of materials to the requirements of MIL-I-25135 or AMS-2644 shall be verified, normally by a certified report from the supplier. Use of materials not conforming to MIL-I-25135 or AMS-2644 shall be approved by the cognizant engineering organization prior to use and shall be allowed only when materials conforming to MIL-I-25135 or AMS-2644 are inadequate for the particular application. Operators shall be alert to any changes in performance, color, odor, consistency, or appearance of all penetrant materials in use and shall conduct the appropriate checks and tests if they have reason to believe the quality may have deteriorated. Penetrant examination shall be conducted in accordance with this practice only after acceptable quality of materials has been established.

TABLE 1 Tests and Test Frequency

Tests	Frequency	Paragraph
System Performance	Daily	7.8.3
Penetrant Contamination	Daily	7.8.2.1
Developer Contamination (Aqueous: Soluble and Suspendable)	Daily	7.8.2.5
Developer Concentration (Aqueous: Soluble and Suspendable)	Weekly	7.8.2.6
Developer Condition (Dry)	Daily	7.8.2.4
Water Wash Pressure[A]	Each shift	7.8.5.4
Water Wash Temperature[A]	Each shift	7.8.5.4
Back Light Intensity	Daily	7.8.5.1
Inspection Area Cleanliness[A]	Daily	7.8.5.3
Water-Based Penetrant Water Concentration	Weekly	7.8.2.2
Non-Water-Based Penetrant (Method A) Water Content	Monthly	7.8.2.2
Emulsifier Concentration (Hydrophilic)	Weekly	7.8.2.7
Penetrant Sensitivity[B]	Weekly	7.8.4.3
Fluorescent Brightness (Test Method E 1135)[B]	Quarterly	7.8.4.1
Penetrant Removability[B]	Monthly	7.8.4.2
Emulsifier Removability[B]	Monthly	7.8.4.4
Emulsifier Water Content (lipophilic)	Monthly	7.8.2.3
Drying Oven Calibration[C]	Quarterly	7.8.5.5
Light Meter Calibration[C]	Semiannually	7.8.5.2

[A] Need not be recorded.
[B] These checks can be combined and performed during the system performance check in accordance with 7.8.4.
[C] The maximum time between verifications may be reduced or extended when substantiated by actual technical/reliability data.

7.8.2 *Material Checks (In-Use)*—The tests identified in 7.8.2.1 through 7.8.4, whichever is applicable, shall be conducted on in-use materials at frequencies specified in Table 1 and recorded. Records shall be maintained in a specified location for audit by the cognizant engineering organization. Materials that are not recovered or reused, or both, such as materials packaged in aerosol containers, are not subject to the requirements of 7.8.2.

7.8.2.1 *Penetrant Contamination*—The in-use penetrant materials shall be viewed at intervals specified in Table 1 to determine if any of the following conditions are evident: precipitates, waxy deposits, white coloration, separation of constituents, surface scum, or any other evidence of contamination or breakdown. When any of the above conditions are detected the material shall be discarded or modified in accordance with the manufacturers' instructions.

7.8.2.2 *Water Content (Method A Penetrants Only)*—Water content of Method A penetrants shall be checked using the appropriate test method at the frequency specified in Table 1. The concentration of Method A, water-based penetrant shall be checked with a refractometer at the frequency specified in Table 1. The water content must be maintained according to manufacturer's recommendation. Water content of Method A, non-water-based penetrant shall be checked in accordance with Test Method D 95 or Karl Fischer Method as described in Annex A1. If the water content of the in-use penetrant exceeds 5 %, then either discard the penetrant or add sufficient unused penetrant to reduce the water content below 5 %.

7.8.2.3 *Water Content (Lipophilic Emulsifier)*—Water content shall be checked in accordance with Test Method D 95 or Karl Fischer method as described in Annex A1 at the frequency specified in Table 1. If the used emulsifier exceeds the water content of the original emulsifier by more than 5 % it shall be discarded or corrected, as appropriate.

7.8.2.4 *Developer Condition (Dry)*—Dry developer shall be checked at the frequency specified in Table 1 to ensure it is fluffy and not caked. Caked dry developer is unsatisfactory and shall be replaced. For dry developer that is recycled, ten or more fluorescent specks observed under black light in a 4-in. (10-cm) diameter circle when a sample is spread into a thin layer on a flat surface, is unsatisfactory.

7.8.2.5 *Developer Contamination (Aqueous: Soluble and Suspendable)*—Aqueous developers shall be checked for fluorescence, as appropriate, and coverage at the frequency specified in Table 1. Immerse a clean aluminum panel, about 3 by 10 in. (8 by 25 cm) and remove for drying and observation under a black light. Failure to uniformly wet the panel or observed fluorescence is unsatisfactory and the developer shall be replaced.

7.8.2.6 *Developer Concentration (Aqueous: Soluble and Suspendable)*—Aqueous developer concentration shall be

checked with a hydrometer at the frequency specified in Table 1. Concentration shall be in accordance with the developer supplier's recommendation.

7.8.2.7 *Emulsifier Concentration (Hydrophilic)*—Concentration of emulsifier solutions shall be checked with a refractometer at the frequency specified in Table 1 for conformance to 7.3.4.2. A longer period may be used if a plan justifying this extension is prepared by the NDT facility and approved by the cognizant engineering organization.

7.8.3 *System Performance*—The penetrant system shall be checked at the frequency specified in Table 1 for performance. The check shall be made with known defect standards. The check shall be performed by processing the known defect standard through the system using appropriate processing parameters and comparing the indications thus obtained to those obtained with unused samples of the same materials. This comparison may be made with other records of previously obtained indications or with a similar known defect standard processed with the unused materials. When the performance of the in-use materials falls below the performance of the unused materials, the in-use material quality shall be checked in accordance with the appropriate sections in 7.8.4 prior to conducting any penetrant examination in accordance with this practice. The unacceptable used material shall be discarded.

7.8.3.1 *Known Defect Standards*—The selection and procedures for the maintenance of known defect standards shall be approved by the cognizant engineering organization. The defects in the standard shall be capable of demonstrating unsatisfactory system performance. The maintenance procedures shall ensure that cleaning of the standards between usages is adequate and that physical changes in the standard that make it unsuitable for use can be detected.

7.8.4 *System Checks*—The test specified in 7.8.4.1 through 7.8.4.4 shall be made at frequencies specified in Table 1. These periodic checks of penetrant materials may be waived if the known defect standard(s) selected for the system performance check adequately monitor the serviceability of the penetrant materials and the results of the daily performance checks are documented in sufficient detail to allow an audit to detect deterioration of performance below satisfactory levels.

7.8.4.1 *Penetrant Brightness*—Brightness tests of in-use fluorescent penetrants shall be conducted at the frequency specified in Table 1. Tests shall be in accordance with Test Method E 1135 with a sample of the unused penetrant serving as the reference. Brightness values less than 90 % of the unused penetrant brightness are unsatisfactory and the in-use penetrants shall be discarded or otherwise corrected, as appropriate.

7.8.4.2 *Penetrant Removability (Method A Only)*—The removability of Method A penetrants shall be tested at the frequency specified in Table 1. The test piece specified in MIL-I–25135 or AMS-2644 shall be used for this test. Tests shall be by normal wash parameters used when processing production parts with a sample of the unused penetrant serving as a reference or in accordance with MIL-I-25135 or AMS-2644. If the removability is noticeably less than the reference, the in-use penetrant shall be replaced.

7.8.4.3 *Penetrant Sensitivity*—The sensitivity of penetrants shall be checked in accordance with the procedures of 7.8.3 when the in-use penetrant is used with the unused emulsifier, if applicable, and unused developer if applicable and compared to the results obtained using the unused penetrant, unused emulsifier, if applicable, and unused developer, if applicable. Sensitivity of the in-use penetrant noticeably less than the reference is unsatisfactory.

7.8.4.4 *Emulsifier Removability*—Removability of the in-use emulsifier shall be tested at the frequency specified in Table 1 by normal wash parameters used when processing production parts with a sample of the unused emulsifier serving as a reference or in accordance with MIL-I-25135 or AMS-2644. The test piece specified in MIL-I-25135 or AMS-2644 shall be used for this test. The in-use emulsifier will be used with the unused penetrant and compared to the reference system of unused emulsifier used with the unused penetrant. Removability less than that of the reference system is unsatisfactory.

7.8.5 *Equipment Checks*—The following equipment checks shall be made at frequencies specified in Table 1 and recorded. Records shall be maintained in a specified location and available for audit by the cognizant engineering organization. The calibration of equipment shall be traceable to the National Institute of Standards and Technology (NIST) or other recognized national standards, where applicable.

7.8.5.1 *Black Lights*—Blacklights, portable, hand-held, permanently mounted or fixed, which are used to inspect parts, shall be checked for output at the frequency specified in Table 1 and after bulb replacement. A longer period may be used if a plan justifying this extension is prepared by the NDT facility or its designated delegate. Minimum acceptable intensity is 1000 $\mu w/cm^2$ (10 W/m^2) at 15 in. (38.1 cm) from the front of the filter to the face of the sensor. Blacklights shall be checked periodically for cleanliness and integrity and shall be cleaned, repaired or replaced as appropriate.

7.8.5.2 *Light Meters*—Both the black and visible light meters shall be calibrated in accordance with MIL-STD-45662 or ANSI/NCSL Z540-1.

7.8.5.3 *Inspection Area*—The inspection area for stationary systems shall be clean and free from excessive fluorescent contamination and residual visible light background.

7.8.5.4 *Water Wash Operating Pressures/Temperatures*—Indicators and controls shall be checked at the start of each shift to ensure proper settings. Those indicators displaying out-of-control settings shall be adjusted to the proper settings. Indicators and controls shall be calibrated at intervals in accordance with MIL-STD-45662 or ANSI/NCSL Z540-1 or ISO 10012-1.

7.8.5.5 *Drying Oven Calibration*—The temperature controlling device and the temperature indicating device, if separate from the controller, on the drying oven shall be calibrated to the requirements of 6.6.2 at frequencies established in accordance with the requirements of MIL-STD-45662 or ANSI/NCSL Z540-1 or ISO 10012-1.

7.9 *Marking and Identification*—Components successfully passing the penetrant examination shall be identified and marked as follows:

7.9.1 *Marking*—Marking shall be applied in a manner and location that is harmless to the component, or its intended

function, and to preclude removal, smearing, or obliteration by subsequent handling. When subsequent processing would remove such identification, the records accompanying the component shall be marked or shall specify components to the applicable documents. The methods of marking are listed in 7.9.2. Marking shall conform to MIL-STD-792.

7.9.2 *Impression Stamping Ink Stamping, Dyeing, Laser Marking, Vibro Engraving, Peening or Etching*—The specific method to be used shall be specified in the contract document (purchase order, drawing, specification, etc.). If not specified, ink stamping shall be used. Marking shall be located in areas adjacent to the part number or an area specified by the contract documents.

7.9.3 *Other Identification*—Other means of identification, such as tagging, may be applied when the construction, finish, or functional requirements of the component preclude etching, dyeing, or stamping. Items such as bolts, nuts, or other small parts may be identified by conspicuously marking each package.

7.9.4 *Symbols*—Each component that has successfully passed examination shall be marked as follows:

7.9.4.1 When etching or stamping is applicable, symbols shall be used. The stamping may contain an identification symbol or supplier number of the facility and a unique number or symbol identifying the examiner. Except for specialized applications, use the symbol "P" to denote 100 % examination. All components, in the lot sampled, accepted on sampling basis shall be marked with the symbol "P" enclosed by an ellipse.

7.9.4.2 When dyeing is used, maroon dye shall be used to denote components accepted on a 100 % examination basis. Yellow dye shall be used to denote a sampling basis when sampling is permitted.

8. Keywords

8.1 dye liquid penetrant inspection; dye penetrant inspection; fluorescent liquid penetrant inspection; fluorescent penetrant inspection; liquid penetrant inspection; liquid penetrant examination; liquid penetrant testing; nondestructive; nondestructive evaluation; nondestructive examination; nondestructive inspection; nondestructive testing; penetrant examination; penetrant inspection; penetrant testing

ANNEX

(Mandatory Information)

A1. METHOD FOR MEASURING WATER CONTENT

A1.1 Scope and Application—This modified Karl Fischer volumetric procedure is a practical alternative to Test Method D 95 for undiluted hydrophilic emulsifiers and water contamination of in-use lipophilic emulsifiers and Method A penetrants. The amount of sample used is adjusted to meet the water equivalent capacity of the titration agent employed (1 ml = 5 mg H_2O). For most materials required to meet the five percent (5 %) maximum allowable water content limit, 0.5 to 1.0 g sample size is sufficient.

A1.2 Apparatus:

A1.2.1 *Buret*, glass, 50-ml,

A1.2.2 *Flask*, wide-mouth Erlenmeyer type, 250-ml,

A1.2.3 *Pipets*, volumetric, two, 10-ml,

A1.2.4 *Weighing scale*, reads to at least two decimal places, and

A1.2.5 *White paper*.

A1.3 Reagents:

A1.3.1 *Buffer solution,*[10] Hydranal (Riedel de Haen) or Hydra-Point (J.T. Baker), 500 ml,

A1.3.2 *Titrant,*[10] Hydranal Composite 5 (Riedel de Haen) or Hydra-Point Titrant 5, 1 L, and

A1.3.3 *Methanol*, reagent grade, 500 mL.

A1.4 Analytical Procedure:

A1.4.1 Charge buret with Hydranal titrant.

A1.4.2 Pipet 10 mL of methanol into clean dry Erlenmeyer flask.

A1.4.3 Pipet 10 mL of Hydranal buffer into the same flask and gently swirl to mix.

A1.4.4 Place white paper below buret. Place the flask under the buret and slowly titrate, with gently swirling the Hydranal titrant into the flask until a light yellow-brown color persists (about 3 mL).

A1.4.5 Record titrant reading.

A1.4.6 Place the flask on balance and add about 0.5 g of test sample, and record weight. Gently swirl flask to mix sample.

A1.4.7 Place flask under buret and titrate back to the same yellow-brown color and record the reading.

A1.4.8 Repeat and average % H_2O readings.

A1.5 Calculate Water Content as follows:

$$\%\ H_2O = [\text{consumption titrant} \times \text{titer value} \times 100] \div \text{sample weight} \quad \text{(A1.1)}$$

where:

consumption = second buret reading of Hydranal Composite 5 Titrant minus the first buret reading, mL,

titer value = 5 mg/ml H_2O, mg/mL, and

sample weight = weight of sample added, mg.

A1.6 Repeat and average % H_2O readings.

[10] The sole source of supply for the reagents known to the committee at this time is Crescent Chemical Company, Inc., 1324 Motor Parkway, Hauppauge, NY 11788. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

Anexo 2. Norma ASTM E 1444. Práctica Recomendada para el Examen por Partículas Magnéticas.

Designation: E 1444 – 94a

An American National Standard

Standard Practice for Magnetic Particle Examination[1]

This standard is issued under the fixed designation E 1444; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice establishes minimum requirements for magnetic particle examination used for the detection of surface or slightly subsurface discontinuities in ferromagnetic material. This practice is intended as a direct replacement of MIL-STD-1949. Guide E 709 can be used in conjunction with this practice as a tutorial.

1.2 The magnetic particle examination method is used to detect cracks, laps, seams, inclusions, and other discontinuities on or near the surface of ferromagnetic materials. Magnetic particle examination may be applied to raw material, billets, finished and semifinished materials, welds, and in-service parts. Magnetic particle examination is not applicable to nonferromagnetic metals and alloys such as austenitic stainless steels.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents form a part of this standard practice to the extent specified herein.

2.2 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 456 Specification for Magnetic Particle Inspection of Large Crankshaft Forgings[2]

D 96 Test Methods for Water and Sediment in Crude Oil by the Centrifuge Method (Field Procedure)[3]

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[4]

E 709 Guide for Magnetic Particle Examination[4]

E 1316 Terminology for Nondestructive Examinations[4]

2.3 *ASNT Document:*

SNT-TC-1A Recommended Practice and Supplement Magnetic Particle Inspection[5]

2.4 *Society of Automotive Engineers (SAE)-AMS Documents:*[6]

AMS 2300 Premium Aircraft-Quality Steel Cleanliness Magnetic Particle Inspection Procedure[7]

AMS 2301 Aircraft Quality Steel Cleanliness Magnetic Particle Inspection Procedure[7]

AMS 2303 Aircraft Quality Steel Cleanliness Martensitic Corrosion Resistant Steels Magnetic Particle Inspection Procedure[7]

AMS 2641 Magnetic Particle Inspection Vehicle[7]

AMS 3040 Magnetic Particles, Nonfluorescent, Dry Method[7]

AMS 3041 Magnetic Particles, Nonfluorescent, Wet Method, Oil Vehicle, Ready-To-Use[7]

AMS 3042 Magnetic Particles, Nonfluorescent, Wet Method, Dry Powder[7]

AMS 3043 Magnetic Particles, Nonfluorescent, Wet Method, Oil Vehicle, Aerosol Packaged[7]

AMS 3044 Magnetic Particles, Fluorescent, Wet Method, Dry Powder[7]

AMS 3045 Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Ready-To-Use[7]

AMS 3046 Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Aerosol Packaged[7]

AMS 5355 Investment Castings[7]

2.5 *Federal Standards:*[6]

FED-STD-313 Material Safety Data Sheets, Preparation and the Submission of[8]

FED-STD-595 Colors[8]

2.6 *Military Standards:*[6]

MIL-STD-1907 Inspection, Liquid Penetrant and Magnetic Particle Soundness Requirements for Materials, Parts, and Weldments[8]

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[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.03 on Liquid Penetrant and Magnetic Particle Methods.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 05.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[6] Copies of standards, specifications, drawings, and publications required by manufacturers in connection with specification acquisition should be obtained from the contracting activity or as directed by the contracting officer.

[7] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

[8] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[8]
MIL-STD-1949 Magnetic Particle Inspection, Method of[8]
MIL-STD-2175 Castings, Classification and Inspection of[8]
MIL-STD-45662 Calibration Systems Requirements
MIL-I-83387 Inspection Process, Magnetic Rubber[8]
DoD-F-87935 Fluid, Magnetic Particle Inspection, Suspension (Metric)[8]

2.7 *OSHA Document:*[9]
29CFR 1910.1200 Hazard Communication

2.8 *DoD Contracts*—Unless otherwise specified, the editions of the documents that are DoD adopted are those listed in the issue of the DoDISS (Department of Defense Index of Specifications and Standards) cited in the solicitation.

2.9 *Order of Precedence*—In the event of conflict between the text of this practice and the referenced documents cited herein, the text of this practice takes precedence.

3. Terminology

3.1 *Definitions*—The definitions relating to magnetic particle examination, which appear in Terminology E 1316, shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *alternating current (ac)*—an electrical current that reverses its direction of flow at regular intervals.

3.2.2 *ambient light*—the visible light level measured at the specimen surface with the black light(s) on.

3.2.3 *contracting agency*—a prime contractor, subcontractor, or government agency procuring magnetic particle inspection services.

3.2.4 *gauss (G)*—the unit of flux density or induction in the cgs electromagnetic unit system (1 G = 10^{-4} Tesla (T); in air, 1 G is equivalent to 1 oersted (Oe), which equals 79.58 A/m).

3.2.5 *head shot*—the production of circular magnetization by passing current directly through the part being inspected, or central conductor, while being held in contact with the head stocks in a horizontal wet machine.

3.2.6 *magnetic flux*—a conceptualization of the magnetic field intensity based on the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet. The magnetic field lies in the direction of the flux lines and has an intensity proportional to the line density.

3.2.7 *magnetization*—the process by which the elementary magnetic domains of a material are predominantly aligned in one direction.

3.2.8 *retentivity*—the ability of a material to retain magnetism after the magnetizing force has been removed.

4. Significance and Use

4.1 Magnetic particle examination consists of magnetizing the area to be inspected, applying suitably prepared magnetic particles while the area is magnetized, and subsequently interpreting and evaluating any resulting particle accumulations. Maximum detectability occurs when the discontinuity is positioned perpendicular to the magnetic flux. In order to detect discontinuities in all directions, at least two magnetic fields, perpendicular to one another in a plane parallel to the surface being inspected, shall be used, except when specifically exempted by the contracting agency.

5. General Practice

5.1 *Acceptance Requirements*—The acceptance requirements applicable to the part or group of parts shall be incorporated as part of the written procedure either specifically or by reference to other applicable documents, such as MIL-STD-1907, containing the necessary information. Applicable drawings or other documents shall specify the acceptance size and concentration of discontinuities for the component, with zoning of unique areas as required by design requirements. These acceptance requirements shall be as approved on or as specified by the contracting agency. Methods for establishing acceptance requirements for large crankshaft forgings are covered in Specification A 456. Methods for establishing requirements for steel forgings are covered in Test Method A 275/A 275M. Methods for classifying metal castings are given in MIL-STD-2175 and AMS 5355. MIL-STD-1907 provides a classification scheme for ferromagnetic forgings, castings, extrusions, and weldments.

5.1.1 *Aircraft-Quality Steel Cleanliness*—The examination of aircraft-quality steel for cleanliness using magnetic particle examination shall be as specified in AMS 2300, 2301, or 2303 as appropriate to the type of steel being inspected. However, inspection of parts fabricated from this material shall be in accordance with the requirements of this practice.

5.2 *Personnel Qualification*—Personnel performing examinations in accordance with this practice shall be qualified and certified in accordance with ASNT Personnel Qualification SNT-TC-1A or MIL-STD-410 for military purposes, or as specified in the contract or purchase order.

5.3 *Agency Qualification*—The agency performing the testing or examination shall meet, as a minimum, the requirements of Practice E 543.

5.4 *Written Procedure*—Magnetic particle examination shall be performed in accordance with a written procedure applicable to the parts or group of parts under testing. The procedure shall be in accordance with the requirements and guidelines of this practice. The procedure shall be capable of detecting the smallest rejectable discontinuities specified in the acceptance requirements. The written procedure may be general if it clearly applies to all of the specified parts being tested and meets the requirements of this practice. All written procedures shall be approved by an individual qualified and certified at Level III for magnetic particle examination in accordance with 5.2. Procedures shall be submitted to the contracting agency when requested.

5.4.1 *Elements of the Written Procedure*—The written procedure shall include at least the following elements, either directly or by reference to the applicable documents:

5.4.1.1 Procedure identification number and the date it was written;

5.4.1.2 Identification of the parts to which the procedure

[9] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

applies; this shall include the material and alloy of which the parts are fabricated;

5.4.1.3 Sequence of magnetic particle examination as related to manufacturing process operation, if applicable;

5.4.1.4 Identification of test parts used for system performance verification (see 7.1.2 and 7.1.3);

5.4.1.5 Areas of the part to be examined (include an illustration–either sketch or photo);

5.4.1.6 Part preparation required before testing;

5.4.1.7 Directions for positioning the item with respect to the magnetizing equipment;

5.4.1.8 The type of magnetizing current and the equipment to be used;

5.4.1.9 Method of establishing the magnetization (head, coil, prods, yoke, cable wrap, etc.);

5.4.1.10 Directions of magnetization to be used, the order in which they are applied, and any demagnetization procedures to be used between shots;

5.4.1.11 The current level, or the number of ampere turns, to be used and the duration of its application;

5.4.1.12 Type of magnetic particle material (dry or wet, visible or fluorescent, etc.) to be used and the method and equipment to be used for its application and, for the case of wet particles, the particle concentration limits;

5.4.1.13 Type of records and method of marking parts after examination;

5.4.1.14 Acceptance requirements, to be used for evaluating indications and disposition of parts after evaluation; and

5.4.1.15 Postinspection demagnetization and cleaning requirements.

5.5 *Examination Sequence*—When magnetic particle examination is specified, it shall be performed after the completion of operations that could cause surface or near-surface defects. These operations include, but are not limited to, forging, heat treating, plating, passivation, cold forming, welding, grinding, straightening, machining, and proof loading. Unless otherwise approved by the contracting agency or as approved in 6.1.3, production parts shall be magnetic particle inspected before the application of any coatings. Also, parts heat treated to an ultimate tensile strength of 180 ksi or higher that are heat treated and subsequently electroplated shall be inspected after the electroplating operation.

5.6 *Record of Examination*—The results of all magnetic particle inspections shall be recorded. All recorded results shall be identified, filed, and made available for review by the contracting agency upon request. Records shall provide for traceability to the specific part or lot inspected, and they shall identify the inspection contractor or facility and the procedures used in the inspection, the lot size, and the number of parts accepted.

5.7 *Lighting*:

5.7.1 *Visible Light*—Visible light shall be used when examining with nonfluorescent particles. The intensity of the visible light at the surface of the part undergoing examination shall be maintained at a minimum of 100 fc (1000 lx). The intensity measurement shall be conducted with a suitable illuminance meter with a photopic spectral response.

5.7.1.1 *Ambient Visible Light*—Unless otherwise specified, fluorescent magnetic particle examinations shall be performed in a darkened area with a maximum ambient visible light level of 2 fc (20 lx) measured at the part surface.

5.7.1.2 *Special Visible Internal Light Source*—When examinations of internal surfaces must be performed using special visible light sources, the image produced must have sufficient resolution to effectively evaluate the required discontinuities. Light intensity shall be measured at the expected working distance of the equipment.

5.7.2 *Black Lights*—All black lights shall be checked at the intervals specified in Table 1, and after bulb replacement, for output. A longer period may be used if a plan justifying this extension is prepared by the nondestructive testing facility and approved by the contracting agency. The minimum acceptable intensity is 1000 $\mu W/cm^2$ at the part being examined. Black light reflectors and filters shall be checked daily for cleanliness and integrity. Damaged or dirty reflectors or filters shall be replaced or otherwise corrected as appropriate.

5.7.3 *Internal Part Examination*—Where lamps are physically too large to directly illuminate the examination surface, special lighting shall be used. Internal features such as bores, holes, and passages less than 0.5 in. (12.5 mm) nominal diameter shall not require magnetic particle examination unless otherwise specified by the contracting agency.

5.8 *Materials*:

5.8.1 *Dry Particle Requirements*—Dry particles shall meet the requirements of AMS 3040. In applying AMS 3040, the particles shall show indications as listed in Table 2 on the test ring specimen of Fig. 1 using the following procedure:

5.8.1.1 Place a conductor with a diameter between 1 and 1.25 in. (25 and 31 mm) and a length longer than 16 in. (40 cm) through the center of the ring. Center the ring on the length of the conductor. Magnetize the ring circularly by passing the current specified in Table 2 through the conductor. Using a squeeze bulb or other suitable applicator, apply the particles to the surface of the ring while the current is flowing. Examine the ring within 1 min after current application under a visible light of not less than 100 fc (1000 lx). The number of hole indications shall meet or exceed those specified in Table 2.

5.8.2 *Wet Particle Requirements*—Wet particles shall meet the requirements of AMS 3041, 3042, 3043, 3044, 3045, or 3046, as applicable. In applying these specifications, the particles shall show indications as listed in Table 2 on the test

TABLE 1 Required Verification Intervals

Item	Maximum Time Between Verification
Lighting:	
Black light intensity	1 day
Ambient light intensity	1 day
Visible light intensity	1 day
System Performance using the test piece or ring specimen of Fig. 1	1 day
Wet particle concentration	8 hours, or every shift change
Water break test	1 day
Wet particle contamination	1 week
Equipment calibration check:	
Gaussmeter reading (Teslameter) zero	Prior to Use
Gaussmeter (Teslameter) accuracy	6 months
Ammeter accuracy	6 months
Timer control	6 months
Quick break	6 months
Dead weight check	6 months

TABLE 2 Required Indications When Using the Ring Specimen of Fig. 1

Particles Used	Central Conductor FWDC Amperage	Minimum Number of Holes Indicated
Wet suspension, Fluorescent, or Nonfluorescent	1400	3
	2500	5
	3400	6
Dry powder	1400	4
	2500	6
	3400	7

ring specimen of Fig. 1 using the following procedure:

5.8.2.1 Place a conductor with a diameter between 1 and 1.25 in. (25 and 31 mm) and a length longer than 16 in. (40 cm) through the center of the ring. Center the ring on the length of the conductor. Magnetize the ring circularly by passing the current specified in Table 2 through the conductor. Apply the suspension to the ring using the continuous method. Examine the ring within 1 min after current application (examination of nonfluorescent baths shall be conducted under visible light of not less than 100 fc (1000 lx); examination of fluorescent baths shall be conducted under a black light of not less than 1000 $\mu W/cm^2$). The number of hole indications shall meet or exceed those specified in Table 2.

5.8.3 *Suspension Vehicles*—The suspension vehicle for the wet method shall be a light petroleum distillate conforming to AMS 2641 (Type I) or DoD-F-87935, or a suitably conditioned water that conforms to the requirements of 5.8.4. When approved by the contracting agency, AMS 2641 (Type II) may be used. The flash point and viscosity shall be in accordance with the requirements of AMS 2641 or DoD-F-87935. The background fluorescence of the suspension vehicle shall be less than the limit specified in DoD-F-87935.

5.8.4 *Conditioned Water Vehicle*—When water is used as a suspension vehicle for magnetic particles, it shall be conditioned suitably to provide for proper wetting, particle dispersion, and corrosion protection. Proper wetting shall be determined by a water break test (see 7.1.4.2). Smoother test surfaces generally require that a greater percent of wetting agent be added than rough surfaces. Nonionic wetting agents are recommended. However, wetting agent additions shall be controlled in all cases by pH measurements to limit the alkalinity of the suspension to a maximum pH of 10.0 and the acidity to a minimum pH of 6.0.

5.8.5 *Particle Concentration*—The concentration of particles in the test bath shall be as specified in the written procedure. Particle concentrations outside of the range of 0.1 to 0.4 mL in a 100-mL bath sample for fluorescent particles and 1.2 to 2.4 mL for nonfluorescent particles shall not be used unless authorized by the contracting agency. Fluorescent particles and nonfluorescent particles shall not be used together.

6. Specific Practice

6.1 *Preparation of Parts for Test*:

6.1.1 *Preinspection Demagnetization*—The part shall be demagnetized before examination if prior operations have produced a residual magnetic field that may interfere with the examination.

6.1.2 *Surface Cleanliness and Finish*—The surface of the part to be inspected shall be essentially smooth, clean, dry, and free of oil, scale, machining marks, or other contaminants or conditions that might interfere with the efficiency of the inspection.

6.1.3 *Coatings*—Magnetic particle examination shall not be performed with coatings in place that could prevent the detection of surface defects in ferromagnetic substrate. Such coatings normally include paint or chrome plate greater than 0.003 in. (0.08 mm) in thickness and ferromagnetic coatings such as electroplated nickel greater than 0.001 in. (0.03 mm) in thickness. If coatings greater than these limits are present during examination, it must be demonstrated that the minimum rejectable discontinuities can be detected through the maximum coating thickness applied. When such coatings are nonconductive, they must be removed where electrical contact is to be made. In high stress applications when detection of fine defects such as grinding cracks and nonmetallic stringers is required, examination with coatings in place shall be performed only when it has been verified that the minimum rejectable discontinuities can be detected in the presence of the coating.

6.1.4 *Plugging and Masking*—Unless otherwise specified by the contracting agency, small openings and oil holes leading to passages or cavities that could entrap or remain contaminated with inspection media shall be plugged with a suitable nonabrasive material that can be removed readily and, in the case of engine parts, is soluble in oil. Effective masking shall be used to protect those components, such as certain nonmetallics, that may be damaged by contact with the suspension.

6.2 *Magnetization Methods*:

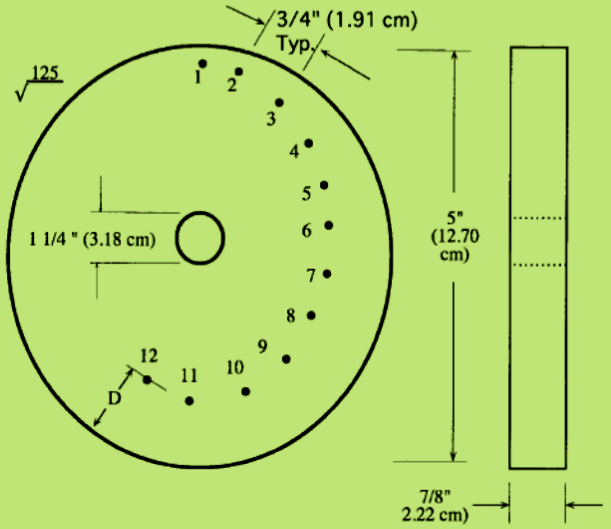
6.2.1 *Types of Magnetizing Current*—The types of currents used for magnetic particle examination are full-wave rectified alternating current (3 or 1 phase), half-wave rectified alternating current, and alternating current. The equipment used shall fulfill the magnetizing and demagnetizing requirements adequately, as outlined herein, without damage to the part under testing, and they shall include the necessary features required for safe operation.

6.2.2 *Permanent Magnets*—Permanent magnets are not to be used for magnetic particle examination unless specifically authorized by the contracting agency. When permanent magnets are used, adequate magnetic field strength shall be established in accordance with 7.1.5.4.

6.2.3 *Yokes*—When using yokes (electromagnetic probes) for magnetic particle examination, adequate magnetic field strength shall be established in accordance with 7.1.5.4.

6.2.4 *Magnetizing Current Application*—Alternating current is to be used only for the detection of defects open to the surface. Full-wave rectified alternating current has the deepest possible penetration and must be used for inspection for defects below the surface when using the wet magnetic particle method. Half-wave rectified alternating current is advantageous for the dry powder method because it creates a pulsating unidirectional field that gives increased mobility to the particles.

6.2.5 *Magnetic Field Directions*—Discontinuities are difficult to detect by the magnetic particle method when they make an angle less than 45° to the direction of magnetization. To ensure the detection of discontinuities in any direction, each



Hole	1	2	3	4	5	6	7	8	9	10	11	12
Diameter Note 1	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)
"D" Note 2	0.07 (0.18 cm)	0.14 (0.36 cm)	0.21 (0.53 cm)	0.28 (0.71 cm)	0.35 (0.90 cm)	0.42 (1.08 cm)	0.49 (1.26 cm)	0.56 (1.44 cm)	0.63 (1.62 cm)	0.70 (1.80 cm)	0.77 (1.98 cm)	0.84 (2.16 cm)

Notes:

NOTE 1—All hole diameters are ±0.005 in. (±0.01 cm). Hole numbers 8 thru 12 are optional.
NOTE 2—Tolerance on the D distance is ±0.005 in. (±0.01).
NOTE 3—All dimensions are ±0.03 in. (±0.08) or as noted in Notes 1 and 2.
NOTE 4—All dimensions are in inches, except as noted.
NOTE 5—Material is ANSI 01 tool steel from annealed round stock.
NOTE 6—The ring may be heat treated as follows: Heat to 1400 to 1450°F (760 to 790° C). Hold at this temperature for 1 h. Cool at a maximum rate of 40°F/hr (22°C/hr) to below 1000°F (540°C). Furnace or air cool to room temperature. Finish the ring to RMS 25 and protect from corrosion.

FIG. 1 ANSI KETOS Tool Steel Ring

part must be magnetized in at least two directions at right angles to each other. Depending on part geometry, this may consist of circular magnetization in two or more directions, of both circular and longitudinal magnetization, or of longitudinal magnetization in two or more directions. Exceptions necessitated by part geometry, size, or other factors require specific approval of the contracting agency.

6.2.6 *Multidirectional Magnetization*—Multidirectional magnetization may be used to fulfill the requirement for magnetization in two directions if it is demonstrated that it is effective in all critical areas. Artificial flaws that are etched or machined, as shown by a device equal to Fig. 2, may be used to establish field direction. It is vitally important that the field intensity be balanced in all directions so that one direction does not overwhelm another direction. In using this method, the particle application must be timed so that the magnetization reaches its full value in all directions during the time particles are mobile on the surface under testing (that is, the continuous method).

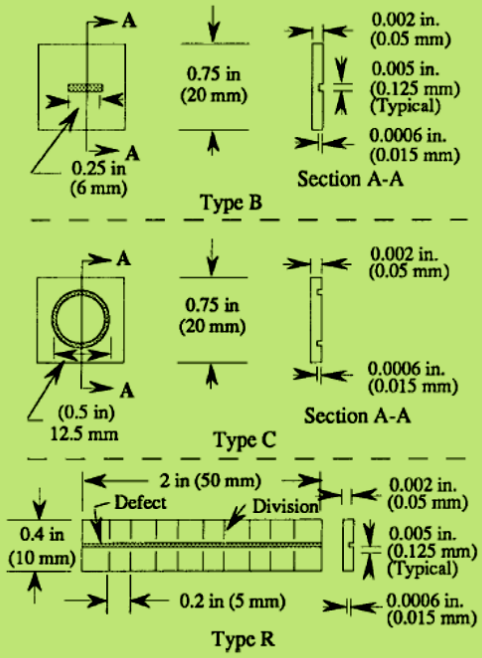
6.2.7 *Direct Magnetization*—Direct magnetization is accomplished by passing current directly through the part under testing. Electrical contact is made to the part using head and tail stock, prods, clamps, magnetic leeches, or by other means. Precaution shall be taken to ensure that the electrical current is not flowing while contacts are being applied or removed and that excessive heating does not occur in the contact area. Unless otherwise specified by the contracting agency, prods shall not be used for the examination of aerospace components (flight hardware) or on finished surfaces.

6.2.8 *Indirect Magnetization*—Indirect part magnetization uses preformed coils, cable wraps, yokes, field flow fixtures, or a central conductor to produce a magnetic field of suitable strength and direction to magnetize the part under test.

6.2.9 *Induced Current Magnetization*—Induced current magnetization (toroidal or circumferential field) is accomplished by inductively coupling a part to an electrical coil to create a suitable current flow in the part as illustrated in Fig. 3. This method is often advantageous on ring-shaped parts with a central aperture and with an *L/D* ratio less than three, especially where the elimination of arcing or burning is of vital importance.

6.3 *Magnetic Field Strength*:

6.3.1 *Magnetic Field Strength*—The applied magnetic field shall have sufficient strength to produce satisfactory indications, but it must not be so strong that it causes the masking of relevant indications by nonrelevant accumulations of magnetic



Examples of artificial shims used in magnetic particle inspection system verification. (Not drawn to scale.) The shims are made of low carbon steel (1005 steel foil). The artificial flaw is etched or machined on one side of the foil to a depth of 30% of the foil thickness. In use, the shims are firmly attached to the test part (e.g. with tape around the edges) with the flaw toward the part.

FIG. 2 Configuration of Artificial Flaws and Their Designation

particles. Factors that determine the required field strength include the size, shape, and material permeability of the part, the technique of magnetization, the method of particle application, and the type and location of the discontinuities sought. Adequate magnetic field strength may be determined by one or a combination of three methods:

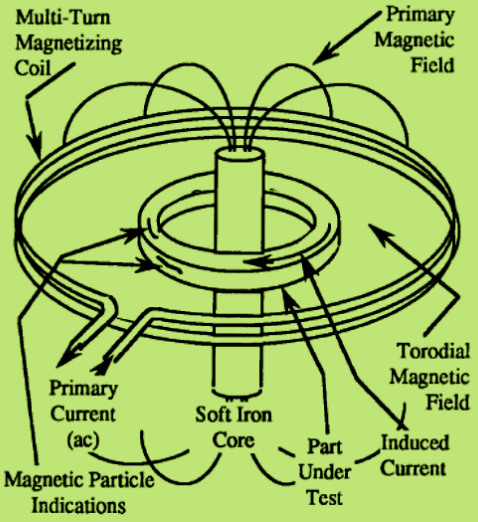
6.3.1.1 By testing parts having known or artificial defects of the type, size, and location specified in the acceptance requirements;

6.3.1.2 By using a Hall effect probe gaussmeter capable of measuring the peak values of the tangent field; and

6.3.1.3 By using the formulas given in 6.3.7.1-6.3.7.4.

6.3.2 When using a Hall effect probe gaussmeter, tangential-field strengths, measured on the part surface, in the range of 30 to 60 G (2.4 to 4.8 kAm^{-1}) peak values are normally adequate magnetization levels for magnetic particle examination. It is important to ensure that field strengths in this range are present in all areas to be inspected on the part.

6.3.3 *Magnetization Current Levels*—The current values given are peak current values and are applied directly to full-wave rectified current. For other types of current, the operator's manual or the equipment manufacturer should be consulted to determine what correction factor, if any, is to be used to convert the meter reading to equivalent peak currents.



The primary current sets up an oscillating field. This primary magnetic field in duces a current in the ring shaped part under test.

FIG. 3 Example of Induced Current Magnetization

6.3.4 *Prod Current Levels*—When using prods on material ¾ in. (19 mm) in thickness or less, 90 to 115 A/in. of prod spacing (3.5 to 4.5 A/mm) shall be used. For material greater than ¾ in. (19 mm) in thickness, 100 to 125 A/in. of prod spacing (4.0 to 5.0 A/mm) shall be used. Prod spacing shall not be less than 2 in. (50 mm) or greater than 8 in. (200 mm). The effective width of the magnetizing field when using prods is one fourth of the prod spacing on each side of a line through the prod centers.

6.3.5 *Direct Circular Magnetization*—When magnetizing by passing current directly through the part (that is, using head shots), the current shall be from 300 to 800 A/in. of part diameter (12 to 32 A/mm). The diameter of the part shall be taken as the greatest distance between any two points on the outside circumference of the part. Currents will normally be 500 A/in. (20 A/mm) or lower, with the higher currents (up to 800 A/in.) being used to inspect for inclusions or to inspect low-permeability alloys such as precipitation-hardened steels. For tests used to locate inclusions in precipitation-hardened steels, even higher currents, up to 1000 A/in. (40 A/mm), may be used.

6.3.6 *Central Conductor Circular Magnetization*—Circular magnetization may be provided by passing current through a conductor that passes through the inside of the part. In this case, alternating current is to be used only when the sole purpose of the test is to inspect for surface discontinuities on the inside surface of the part. If only the inside of the part is to be inspected, the diameter shall be the greatest distance between two points, 180 degrees apart on the inside circumference. Otherwise, the diameter is determined as in 6.3.5. The following two paragraphs cover centrally located and offset central conductors:

6.3.6.1 *Centrally Located Conductor*—When the axis of the central conductor is located near the central axis of the part, the

same current levels as given in 6.3.5 shall apply.

6.3.6.2 *Offset Central Conductor*—When the conductor passing through the inside of the part is placed against an inside wall of the part, the current levels as given in 6.3.5 shall apply, except that the diameter shall be considered the sum of the diameter of the central conductor and twice the wall thickness. The distance along the part circumference (interior) that is effectively magnetized shall be taken as four times the diameter of the central conductor, as illustrated in Fig. 4. The entire circumference shall be inspected by rotating the part on the conductor, allowing for approximately a 10 % magnetic field overlap.

6.3.7 *Longitudinal Magnetization Using Coils*—Longitudinal magnetization is often accomplished by passing current through a coil encircling the part, or section of the part, to be tested (that is, by using a coil shot). This produces a magnetic field parallel to the axis of the coil. For low or intermediate fill factor coils, the effective field extends a distance on either side of the coil center approximately equal to the radius of the coil (see Fig. 5). For cable wrap or high-fill factor coils, the effective distance of magnetization is 9 in. (230 mm) on either side of the coil center (see Fig. 6). For parts longer than these effective distances, the entire length shall be inspected by repositioning the part within the coil, allowing for approximately 10 % effective magnetic field overlap.

6.3.7.1 *Longitudinal Magnetization with Low-Fill Factor Coils*—When the cross-sectional area of the coil is ten or more times the cross-sectional area of the part being inspected, the product of the number of coil turns, N, and the current in amperes through the coil, I, shall be as follows:

(*1*) For parts positioned to the side of the coil:

$$NI = \frac{K}{L/D}\,(\pm 10\,\%) \qquad (1)$$

where:
K = 45 000 A turns,
L = length of the part, and
D = diameter of the part (measured in the same units as the length).

(*2*) For parts positioned in the center of the coil:

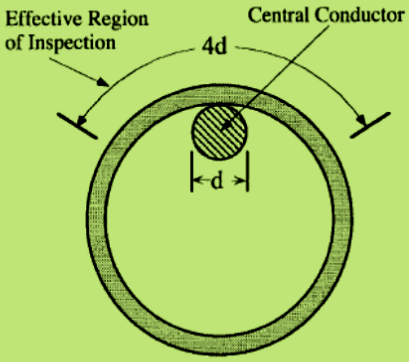


FIG. 4 The Effective Region of Inspection When Using an Offset Central Conductor is Equal to Four Times the Diameter of the Conductor as Indicated

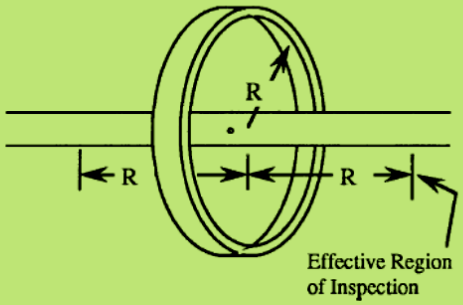


FIG. 5 Effective Region on Inspection for a Low Fill-Factor Coil

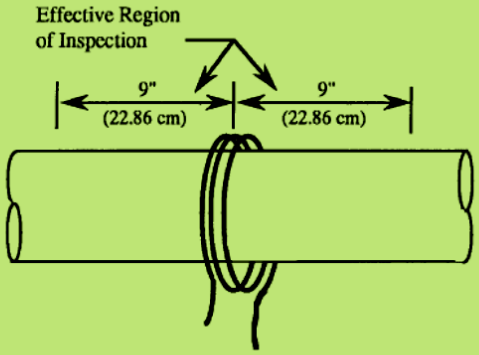


FIG. 6 Effective Region of Inspection for a High Fill-Factor

$$NI = \frac{KR}{(6L/D) - 5}\,(\pm 10\,\%) \qquad (2)$$

where:
R = radius of the coil, mm (or in.),
K = 43 000 A turns per inch if R is measured in inches (1690 A turns per mm),
L = length of the part, and
D = diameter of the part (measured in the same units as the length).

If the part has hollow portions, replace D with D_{eff} as given in 6.3.7.4. These formulas hold only if L/D is greater than 2 and less than 15. If L/D is less than 2, pole pieces (pieces of ferromagnetic material with the same diameter as the part being tested) shall be placed on each end of the part to effectively increase the L/D to 2 or greater. If the L/D is greater than 15, the value of 15 shall be substituted for L/D.

6.3.7.2 *Longitudinal Magnetization with Cable Wrap or High-Fill Factor Coils*—When the cross-sectional area of the coil is less than twice the cross-sectional area (including hollow portions) of the part under testing, the product of the number of coils turns, N, and the current in amperes through the coil, I, shall be as follows:

$$NI = K/\{(L/D) + 2\}\,(\pm 10\,\%) \qquad (3)$$

where:
K = 35 000 A turns,
L = length of the part,

D = diameter of the part (measured in the same units as the length).

If the part has hollow portions, replace D with D_{eff} as given in 6.3.7.4. These formulas hold only if L/D is greater than 2 and less than 15. If L/D is less than 2, pole pieces (pieces of ferromagnetic material with the same diameter as the part being tested) shall be placed on each end of the part to effectively increase the L/D to 2 or greater. If the L/D is greater than 15, the value of 15 shall be substituted for L/D.

6.3.7.3 *Longitudinal Magnetization for Intermediate-Fill Factor Coils*—When the cross-sectional area of the coil is between two and ten times the cross-sectional area of the part being inspected, the product of the number of turns, N, and the current through the coil, I, shall be as follows:

$$NI = (NI)_h(10 - \tau)/8 + (NI)_l(\tau - 2)/8 \quad (4)$$

where:

$(NI)_l$ = value of NI calculated for low-fill factor coils using 6.3.7.1,

$(NI)_h$ = value of NI calculated for high-fill factor coils using 6.3.7.2, and

τ = ratio of the cross-sectional area of the coil to the cross-sectional area of the part (for example, if the coil is 10 in. in diameter and the part is a rod 5 in. in diameter, $\tau = (\pi \times 5^2)/(\pi \times 2.5^2) = 4$).

6.3.7.4 *Calculating the L/D Ratio for a Hollow or Cylindrical Part*—When calculating the L/D ratio for a hollow or cylindrical part, D shall be replaced with an effective diameter, D_{eff}, calculated using the following:

$$D_{eff} = 2[(A_t - A_h)/\pi]^{1/2} \quad (5)$$

where:

A_t = total cross-sectional area of the part, and

A_h = cross-sectional area of the hollow portions of the part.

For cylindrical parts, this is equal to the following:

$$D_{eff} = [(OD)^2 - (ID)^2]^{1/2} \quad (6)$$

where:

OD = outside diameter of the cylinder, and

ID = inside diameter of the cylinder.

6.4 *Particle Application*:

6.4.1 *Continuous Method*—In the dry continuous method, magnetic particles are applied to the part while the magnetizing force is present. In the wet continuous method, the magnetizing current, or force, shall be applied simultaneously with or immediately after diverting the suspension. Application of the magnetic particles (see 6.4.4 and 6.4.5) and the magnetization method shall be as prescribed in the paragraphs referenced herein.

6.4.2 *Residual Magnetization Method*—In the residual magnetization method, the magnetic particles are applied to the test part immediately after the magnetizing force has been discontinued. The residual method is not as sensitive as the continuous method, but it can be useful, for example, in detecting in-service induced fatigue cracks on the surface of material with a high retentivity. It is also useful for the examination of parts in areas in which, because of geometric constraints, the continuous method cannot be used. The residual method shall be used only when specifically approved by the contracting agency or when it has been documented that it can detect defects or artificial defects in test parts. The test parts shall have the same material and processing steps, and similar geometry to, the actual parts being inspected.

6.4.3 *Prolonged Magnetization*—When using polymers, slurries, or paints, prolonged or repeated periods of magnetization are necessary because of lower magnetic particle mobility in the high-viscosity vehicles.

6.4.4 *Dry Magnetic Particle Application*—When using dry particles, the flow of magnetizing current shall be initiated prior to application of the magnetic particles to the surface under testing and terminated after powder application has been completed and any excess blown off. The duration of the magnetizing current shall be at least ½ s, and precaution shall be taken to prevent any damage of the part due to overheating or other causes. Dry powder shall be applied in a manner such that a light, uniform, dust-like coating settles on the surface of the test part while the part is being magnetized. Specially designed powder blowers or shakers using compressed air or hand power shall be used. The applicators shall introduce the particles into the air in a manner such that they reach the part surface in a uniform cloud with a minimum of force. After the powder is applied, and before the magnetizing force is removed, excess powder shall be removed by means of a dry air current with sufficient force to remove the excess particles, but not strong enough to disturb particles held by a leakage field that is indicative of discontinuities. In order to recognize the broad, fuzzy, lightly held powder patterns formed by near-surface discontinuities, the formation of indications must be observed carefully during both powder application and removal of the excess powder. Sufficient time for the formation and examination of indications shall be permitted during the testing process. The dry particle method shall not be used to inspect aerospace components (flight hardware) without specific approval of the contracting agency.

6.4.5 *Wet Magnetic Particle Application*—Fluorescent or nonfluorescent particles suspended in a liquid vehicle at the required concentration shall be applied either by gently spraying or flowing the suspension over the area to be inspected. Proper sequencing and timing of part magnetization and application of particle suspension are required to obtain the proper formation and retention of indications. This generally requires that the stream of suspension be diverted from the part simultaneously with, or slightly before, energizing the magnetic circuit. The magnetizing current shall be applied for a duration of at least ½ s for each application, with a minimum of two shots being used. The second shot should follow the first in rapid succession. It should come after the flow of suspension has been interrupted and before the part is examined for indications. Under special circumstances, such as the use of automated equipment or for critical parts, the ½-s duration and the two-shot requirement may be waived provided it is demonstrated that the test procedure given in 5.4 can detect known defects in representative test parts. Care shall be exercised to prevent any damage to the part due to overheating or other causes. Weakly held indications on highly finished

parts are readily washed away, and hence care must be exercised to prevent high-velocity flow over critical surfaces.

6.4.6 *Magnetic Slurry/Paint Application*—Magnetic paints or slurries are applied to the part with a brush, squeeze bottle, or aerosol can before or during the magnetization operation. This method is for special applications, such as overhead or underwater examination. This method shall be used only when specifically approved by the contracting agency.

6.4.7 *Magnetic Polymer Application*—Polymerizable material containing magnetic particles shall be held in contact with the test part during the period of its cure. Before curing takes place, and while the magnetic particles are still mobile, the part shall be magnetized to the specified level. This requires prolonged or repeated periods of magnetization. This method is for special applications, such as bolt holes, which cannot be tested readily by the wet or dry method, and shall be used only when specifically approved by the contracting agency. MIL-I-83387 establishes the inspection process for magnetic rubber.

6.5 *Evaluation*—Following magnetization and particle application, the parts shall be examined for indications. All indications will be identified as relevant or nonrelevant. Relevant indications will be compared to accept/reject criteria and the parts accepted or rejected accordingly.

6.6 *Recording of Indications*—When required by the written procedure, the location of all rejectable indications shall be marked on the part, and permanent records of the location, direction, and frequency of indications may be made by one or more of the following methods:

6.6.1 *Written Description*—By recording the location, length, direction, and number of indications in sketch or tabular form.

6.6.2 *Transparent Tape*—For dry particle indications, by applying transparent adhesive-backed tape to which the indications will adhere and placing it on an approved form along with information giving its location on the part.

6.6.3 *Strippable Film*—By covering the indication with a spray-on strippable film that fixes the indications in place and placing the resultant reproduction on an approved form along with information giving its location on the part.

6.6.4 *Photography*—By photographing or video recording the indications themselves, the tape, or the strippable film reproduction and placing the photograph in a tabular form along with information giving its location on the part.

6.7 *Postinspection Demagnetization and Cleaning*—Unless directed otherwise by the contracting agency, all parts shall be demagnetized, cleaned, and corrosion protected after examination.

6.7.1 *Demagnetization*:

6.7.1.1 When using ac demagnetization, the part shall be subjected to a field with a peak value greater than, and in nearly the same direction as, the field used during examination. This ac field is then decreased gradually to zero. When using an ac demagnetizing coil, hold the part approximately 1 ft (30 cm) in front of the coil and then move it slowly and steadily through the coil and at least 3 ft (100 cm) beyond the end of the coil. Repeat this process as necessary. Rotate and tumble parts of complex configuration while passing through the field of the coil.

6.7.1.2 When using dc demagnetization, the initial field shall be higher than, and in nearly the same direction as, the field reached during examination. The field shall then be reversed, decreased in magnitude, and the process repeated (cycled) until an acceptably low value of residual field is reached.

6.7.1.3 Whenever possible, parts that have been magnetized circularly shall be magnetized in the longitudinal direction before being demagnetized. After demagnetization, a magnetic field probe or strength meter shall not detect fields with an absolute value above 3 G (240 Am^{-1}) anywhere on the part.

6.7.2 *Postinspection Cleaning*—Cleaning shall be done with a suitable solvent, air blower, or by other means. Parts shall be inspected to ensure that the cleaning procedure has removed magnetic particle residues from coolant holes, crevices, passage ways, etc., since such residue could have an adverse effect on the intended use of the part. Care shall be taken to remove all plugs, masking, or other processing aids that may affect the intended use of the part. Parts shall be protected from any possible corrosion or damage during the cleaning process and shall be treated to prevent the occurrence of corrosion after final inspection.

7. Quality Control

7.1 *System Performance*:

7.1.1 *System Performance Verification*—The overall performance of the magnetic particle examination system, including the equipment, materials, and the lighting environment being used, shall be verified initially and at regular intervals thereafter. The required verification intervals are stated in Table 1. Records of the verification results shall be maintained and retained for the time period specified in the contract. Frequency of calibration for current and voltage measuring devices, ammeter shunts, timers, and gaussmeters used in the verification shall comply with the requirements of MIL-STD-45662 or Table 1, as specified by the cognizant Level III.

7.1.2 *Use of Test Parts with Discontinuities*—A reliable method for inspection system verification is the use of representative test parts containing defects of the type, location, and size specified in the acceptance requirements. If correct magnetic particle indications can be produced and identified in these representative parts, the overall system and inspection procedure is verified. Parts used for verification will be demagnetized, cleaned thoroughly following the examination, and checked under black or visible light, as appropriate to the examination process, to ensure that residual indications do not remain.

7.1.3 *Fabricated Test Parts with Artificial Discontinuities*—When actual production parts with known discontinuities of the type, location, and size needed for verification are not available or are impractical, fabricated test parts with artificial discontinuities shall be used. Artificial discontinuities may be fabricated to meet a particular need or may be commercially available magnetic field indicators or shims as shown in Fig. 2 and Fig. 7. All applicable conditions for the use of such test parts, as described in 7.1.2, shall apply. When commercial devices are used, their magnetic properties, flaw types, and surface condition shall be as close to the production part as possible.

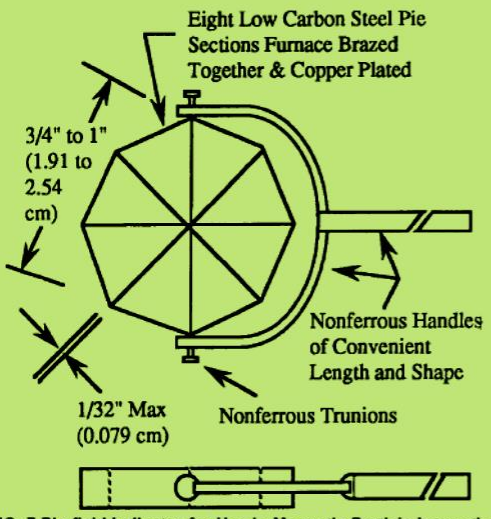


FIG. 7 Pie-field Indicator for Use in Magnetic Particle Inspection System Verification (All Dimensions are in Inches)

7.1.4 *Suspension Vehicle Tests* (Not required for aerosol can solutions):

7.1.4.1 *Concentration/Contamination Tests*—Particle concentration and contamination shall be determined upon start up, at regular intervals thereafter, and whenever the bath is changed or adjusted. The required testing intervals are stated in Table 1.

(1) Determination of Wet Particle Concentration—Agitate the particle suspension a minimum of 30 min to ensure uniform distribution of particles throughout the bath. Place a 100-mL sample of the agitated suspension in a pear-shaped centrifuge tube (of the size and shape specified in Test Methods D 96, except graduated to 1 mL in 0.05-mL increments). Demagnetize the sample and allow the tube to stand undisturbed for at least 60 min if using the petroleum distillate in AMS 2641 or 30 min settling time for conditioned water suspension. Read the volume of settled particles. If the concentration is out of the tolerance stated in the written procedure (or that given in 5.8.5), add the particles or suspension vehicle, as required, and redetermine the particle concentration. If the settled particles appear to be loose agglomerates rather than a solid layer, take a second sample. If the second sample also appears agglomerated, replace the entire suspension. Thirty-minute settling times, or other accelerated tests, may be used if they have been verified to give results equivalent to the procedure described in this paragraph.

(2) Determination of Wet Particle Contamination—Perform the tests specified in 7.1.4.1 (*1*). In addition, for fluorescent baths, examine the liquid above the precipitate with black light. The liquid shall be comparable to the fluorescence of the original solution. Examine the graduated portion of the tube, under both black light (for fluorescent baths only) and visible light (for both fluorescent and nonfluorescent baths), for striations or bands, different in color or appearance. Bands or striations may indicate contamination. If the total volume of the contaminants, including bands or striations, exceeds 30 % of the volume of magnetic particles, or if the liquid is noticeably fluorescent, the bath must be replaced.

7.1.4.2 *Water Break Test*—In this test of water-based vehicles, a clean part with a surface finish the same as the parts to be tested is flooded with the conditioned water, and the appearance of the surface is noted after flooding is stopped. If a continuous even film forms over the entire part, sufficient wetting agent is present. If the film of suspension breaks, exposing bare surface, insufficient wetting agent is present or the part has not been cleaned adequately.

7.1.5 *Equipment Calibration*—Magnetic particle testing equipment shall be checked for performance and accuracy at the time of purchase and at intervals thereafter as given in Table 1, whenever malfunction is suspected or when specified by the contracting agency, and whenever electrical maintenance that might affect equipment accuracy is performed.

7.1.5.1 *Ammeter Accuracy*—To check the equipment ammeter, a calibrated ammeter shall be connected in series with the output circuit. Comparative readings shall be taken at three output levels encompassing the useable range of the equipment. The equipment meter reading shall not deviate by more than ±10 % of full scale from the current value shown by the calibrated ammeter. (When measuring half-wave alternating current, the current values shown by the calibrated dc ammeter readings shall be doubled.) The frequency of the ammeter check is specified in Table 1.

7.1.5.2 *Timer Control Check*—On equipment using a timer to control the current duration, the timer should be checked to within ±0.1 s using a suitable electronic timer.

7.1.5.3 *Magnetic Field Quick Break Check*—On equipment that uses a quick break feature, proper functioning of this circuit shall be verified. The test may be performed using a suitable oscilloscope or other applicable method as specified by the equipment manufacturer.

7.1.5.4 *Dead Weight Check*—Yokes and permanent magnetics (when allowed) shall be dead weight tested at intervals as stated in Table 1. Alternating current yokes shall have a lifting force of at least 10 lb (45 N), with a 2 to 4-in. (50 to 100-mm) spacing between legs. Direct current yokes shall have a lifting force of at least 30 lb (135 N), with a 2 to 4-in. (50 to 100-mm) spacing between legs, or 50 lb (225 N), with a 4 to 6-in. (100 to 150-mm) spacing.

7.2 *Marking of Inspected Parts*—Unless otherwise specified by the contracting agency, parts that have been accepted using magnetic particle examination shall be marked in accordance with the applicable drawing, purchase order, contract, or as specified herein. Marking shall be applied in such a manner and location as to be harmless to the part. The identification shall not be obliterated or smeared by subsequent handling and, when practicable, placed in a location that will be visible after assembly. When subsequent processing would remove the identification, the applicable marking shall be affixed to the record accompanying the finished parts or assembly. Bolts and nuts and other fastener products may be identified as having met the requirements of magnetic particle examination by marking each package conspicuously.

7.2.1 *Impression Stamping, Ink Stamping, Laser Marking,*

or Vibro Engraving—Impression stamping, ink stamping, laser marking, or vibro engraving shall be used when permitted or required by the applicable written procedure, detail specification or drawing, or when the nature of the part is such as to provide for impression stamping of part numbers or other inspector's markings. Impression stamping shall be located only in the area provided adjacent to the part number or inspector's stamp unless otherwise specified by the contracting agency.

7.2.2 *Etching*—When impression stamping, ink stamping, laser marking, or vibro engraving is prohibited, parts shall be etched using an etching fluid or other means and a method of application acceptable to the contracting agency. The etching process and location shall not affect the functioning of the part adversely.

7.2.3 *Dyeing*—When stamping, vibro engraving, or etching is not permissible, identification shall be accomplished by dyeing.

7.2.4 *Other Identification*—Other means of identification, such as tagging, shall be used for parts that have a construction or function precluding the use of stamping, vibro engraving, or etching, as in the case of completely ground or polished balls, rollers, pins, or bushings.

7.2.5 *Identifying Symbols and Color Markings*:

7.2.5.1 *One-Hundred Percent Examination*—When items are examined and accepted by 100 % examination, each item shall be marked as follows:

(1) Dyeing—When dyeing is applicable, a dye of acceptable adherence which is predominantly blue (per FED-STD-595) shall be employed. However, if a color conflict is incurred with any other method, magnetic particle examination can be indicated by two adjacent blue dots or other suitable means.

(2) Stamping, Laser Marking, Vibro Engraving, or Etching—When impression stamping or ink stamping, laser marking, vibro engraving, or etching is used to mark 100 % inspected parts, the letter "M" with a circle around it will be employed.

7.2.5.2 *Lot Inspection*—When items are accepted by means of a sampling procedure, each item of an accepted lot shall be marked as follows:

(1) Dyeing—When dyeing is applicable, a dye of acceptable adherence that is predominantly orange (per FED-STD-595) shall be employed.

(2) Stamping, Vibro Engraving, or Etching—When impression stamping, vibro engraving or etching is used to mark lot inspected parts, the letter" M" shall be employed.

7.3 *Eye Glasses*—When using fluorescent materials, inspectors shall not wear eye glasses that are photochromic or that have permanently darkened lenses. This is not intended to prohibit the use of eyeglasses with lenses treated to absorb ultraviolet light.

7.4 *Safety*—The safe handling of magnetic particles (wet or dry), oil vehicles water baths, and water conditioner concentrates are governed by the suppliers' Material Safety Data Sheets (MSDS). Material Safety Data Sheets, conforming to 29 CFR 1910.1200, or equivalent, must be provided by the supplier to any user and shall be prepared in accordance with FED-STD-313.

7.4.1 *Flammability*—Flash point of oil vehicles shall be in accordance with AMS 2641 or DoD-F-87935. The suppliers' MSDS shall certify the flash point.

7.4.2 *Personnel Hazards*—Precautions against inhalation, skin contact, and eye exposure are detailed in the suppliers' MSDS. These precautions shall be observed.

7.4.3 *Electrical Hazards*—Magnetizing equipment shall be maintained properly to prevent personnel hazards from electrical short circuits. Care must be taken to reduce arcing and the possible ignition of oil baths.

7.4.4 *Black Light*—It is recommended that the intensity of black light incident on unprotected skin or eyes not exceed 1000 $\mu W/cm^2$. Cracked or broken ultraviolet filters shall be replaced immediately. Broken bulbs can continue to radiate ultraviolet energy and must be replaced immediately. Spectacles designed to absorb ultraviolet wavelength radiation are suggested for close, high, black light intensity examination.

7.5 *Dark Adaptation*—Personnel must wait at least 1 min after entering a darkened area for their eyes to adjust to the low-level lighting before performing fluorescent magnetic particle examination.

8. Keywords

8.1 dye; fluorescent; magnetic particle; nondestructive evaluation; nondestructive examination; nondestructive testing

APPENDIX

(Nonmandatory Information)

X1. MEASUREMENT OF TANGENTIAL FIELD STRENGTH

X1.1 Care must be exercised when measuring the tangential applied field strengths specified in 6.3.2. The active area of the Hall effect probe should be no larger than 0.2 in. (5 mm) by 0.2 in. (5 mm) and should have a maximum center location 5 mm from the part surface. The plane of the probe must be perpendicular to the surface of the part at the location of measurement to within 5 degrees. This is difficult to accomplish by hand orientation, therefore the probe should be held in a jig or fixture of some type. If the current is being applied in shots, or if alternating current or half-wave rectified alternating current is being used, the gaussmeter should be set to read the peak value during the shot. The gaussmeter should have a frequency response of 0 to 300 Hz or higher. The direction and magnitude of the tangential field on the part surface can be determined by two measurements made at right angles to each other at the same spot. The gaussmeter probe leads should be shielded or twisted to prevent reading errors due to voltage induced during the large field changes encountered during magnetic particle examination.

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