MAINTENANCE OF AGED MODULAR SHIELDED ENCLOSURES

Maintaining a shielded enclosure within specification over a number of years requires a periodic inspection and correction process. A specific preventive maintenance program is detailed.

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INTRODUCTION

This paper is intended to provide persons involved with the purchase, use, and maintenance of modular shielded enclosures with some insight into the complexities of shielded enclosure repair. The authors feel that there is a need to present this technical subject in an informative way to an audience that typically is not involved in technical issues, as would be the case for a procurement officer attempting to obtain services, a contracting officer monitoring progress, or a facilities engineer who needs to be informed of what is happening to his resources. To accomplish this end, this article has been prepared by two authors; one author is experienced in the shielding industry as a technical consultant, and one author is experienced as a facilities engineer from the user community. The authors have drawn from their combined experiences some comments and presentations that address some of the most frequently faced issues in shielded enclosure maintenance.

Armed with this information, the reader should be able to investigate the condition of a modular shielded enclosure and be able to locate suspect areas where degradation may be occurring. Additionally, the reader will be able to interpret the actions of an enclosure services vendor during negotiations and contract performance and to gain confidence in the contract monitoring aspects of maintenance activity.

TECHNICAL SCOPE

This article addresses technical issues related to the maintenance of aged modular shielded enclosures. There are several variations of modular shielded enclosures that have been on the market over the past few years. This article is limited specifically to the subject of maintaining cell type modular shielded enclosures, enclosures that consist of steel panels laminated to a particle board core joined by clamping hardware framing. The cell type enclosures are the type most frequently encountered by the authors in the course of their work, and this enclosure style is frequently found in facilities throughout the user community.

The common experiences of the authors relate to cell type modular shielded enclosures which operate in moderate to severe humidity environments and which have been in continuous use for periods of more than 3 years and less than 6 years. The enclosures involved in this activity were supplied by two major vendors which are well known in the industry. Each vendor provided the installation. Each of the enclosures involved was installed in a facility as part of a new construction activity.

LOCATING RF LEAKAGE

General Comments

Reading through this article, the user will develop more of an insight into where to look for problems in a modular shielded enclosure. Once the suspect areas have been established, the problem is to pin down the exact location of the leakage. This is not so easy to do. Using the procedures of MIL-STD-285 or NSA 65-6 (these are government specifications that include testing procedures for shielded enclosures), testing can be performed to quantify the amount of leakage as a function of frequency and the approximate area of degradation may be located. The authors use plane wave testing at 1 GHz for rough work and quantification, then perform magnetic field scanning at 1 MHz to close in on the degraded area using the equipment commonly employed in shielded enclosure testing. Usually this procedure will locate the degraded area closely enough so that corrective action can be performed.

Precise Location Search Methods

As usual, there are some important exceptions to this procedure. For example there is the case where leakage is found around the perimeter of a door. The leakage could be caused by dirty fingerstock in the door mating surfaces or it could be due to loose clamping hardware on the door frame only inches away. The situation is illustrated in Figure 1. There is no practical way to determine which location is the actual cause of the leakage using the procedures of NSA 65-6 or MIL-STD-285. Even using small 3- or 4-inch loops will be ineffective since they are too large to achieve any resolution. One alternative would be to rework both

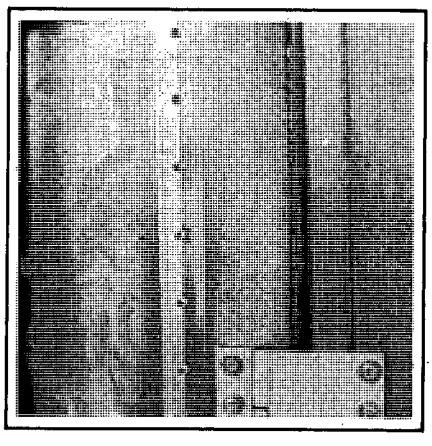

Figure 1. Clamping Hardware Adjacent to Door Mating Surfaces (After Corrective Work).

suspect areas, but that is never time or cost effective when dealing with a penetration as complex as a door.

SELDS

In a situation such as this, there is a need for equipment that can give precise leakage location information, and equipment that can determine the leakage location to dimensions of less than 1 inch. There is equipment commercially available at a reasonable price that offers this kind of resolution capability when used by a skilled operator. This equipment works by inducing RF currents on the surface of a shielded enclosure and then searching on the opposite side of the shielded surface with a small magnetic field probe for evidence of fields caused by circulating RF currents that have penetrated the shield at a defect location. The results are qualitative only. They have no meaning from a calibrated measurement point of view, but the results provide very precise leakage position information. Devices are sold commercially by two vendors that the authors are aware of; both devices are referred to as SELDS test sets. These devices are popularly referred to as *sniffers*. SELDS is an acronym for Shielded Enclosure Leak Detection System. These devices are essential in the construction of welded steel shielded enclosures but can also be very valuable in locating the exact cause of leakage in modular enclosures. The user must remember at all times that the SELDS equipment is not a substitute for calibrated measurement; it is an aid to provide precise position information.

Spectrum Analyzer/EMI Receiver

There are also cases where the surface of the shielded enclosure can be contacted directly with a test probe to track down the sources of RF leakage. This must be done with care to prevent damage to the test equipment. This technique is very effective in the UHF frequency range, far above the frequencies at which the SELDS test equipment operates.

SHIELDED ENCLOSURE DEGRADATION

It has been established in the user community that modular shielded enclosures suffer from performance degradation over a period of time. There is quite a bit of environmental stimulus available in almost any facility that can cause this degradation to occur, and all too often this degradation occurs much faster than one would like. Thermal cycling, humidity cycling, shock, vibration, and electrical overstress all influence the rate of degradation of shielded enclosure performance. All of these factors come into play when a shielded enclosure is installed in a facility cooled and heated by forced air, located in a temperate or tropical climate, subjected to shifting floor loads, subjected to high levels of personnel traffic, supplied by industrial power, or subjected to lightning induced line transients. Virtually every shielded enclosure in use is subject to some combination of these conditions.

A good way to gain an appreciation for what is involved in the aging process and how quickly to expect degradation would be to study the *lifespan* of a shielded enclosure located in ideal conditions. This would provide a baseline for comparisons and establish an *expected* degradation rate. The U.S. Army Construction Engineering Research Laboratory in Champaign, Illinois, did this in the late 70's and a fine report was completed by R. G. McCormack in June of 1981 summarizing this work. This report is approved for public release and is available through the National Technical Information Service. Ask for Report "CERL-TR-M-296."

The study reports the effects of aging on modular shielded enclosures over a 3 year period and includes environmental information. Results of the study showed that "significant degradation of shielding effectiveness occurs with aging, so periodic maintenance will be necessary if optimum shielding is required". This study was conducted under controlled conditions, and the enclosures were not subjected to the rigors of daily usage. This data pertains to portions of a shielded enclosure that are subject to a fairly benign environment. Obviously portions of a shielded enclosure that are subject to a more active environment will degrade at an *accelerated* rate.

The following sections detail experiences with modular shielded enclosure components which have been exposed to the stimulus of an active environment. Each section addresses a specific enclosure component, the symptoms which indicate degradation, and some comments on an approach to correcting observed deficiencies. There are also selected notes on testing and preventive maintenance.

SHIELDED ENCLOSURE CLAMPING HARDWARE

Clamping Hardware Configuration

Many modular shielded enclosures are clamped together with what are referred to as *flat* and *hat* clamping hardware. These terms originate from the cross sectional appearance of the clamping hardware. This hardware is used by almost every manufacturer of modular shielded enclosures, but there are some important exceptions. One manufacturer supplies enclosures that have the inner and outer shielded surfaces isolated by dielectric materials. This requires a unique hardware clamping system that maintains the dielectric isolation of the two shielded surfaces. Another manufacturer provides a single skin (there is only one metal skin and no core material) modular enclosure configuration that is clamped with frame channels and panel tensioners. Another manufacturer of single skin modular enclosures provides a panel clamping system that consists of the familiar flat section clamped to either another flat section or to a rectangular structural tube. In this article, only the flat/hat clamping hardware used in cell type shielded enclosures will be discussed.

Typical Failure Locations

It has been observed that the clamped seams that degrade spectacularly are located where some environmental stimulus accelerates the normally expected rate of degradation. Prime examples are clamping hardware securing a door in place where high levels of shock and vibration are present, clamping hardware near honeycomb ventilation panels where sharp temperature and humidity gradients exist, and clamping hardware securing floor panels where shifting floor loads occur periodically. Particularly important are locations where forced air cooling can cause condensation of atmospheric moisture and where moisture is trapped beneath the enclosure floor. Clamping hardware used to join intersecting shielded planes such as floor/wall or wall/ceiling intersections will often degrade at an accelerated rate; there is considerable mechanical stress at these locations.

It is common practice in facility layout to put all of the doors and penetrations into a shielded enclosure on only one wall of the shield. This is usually done so that all of the utilities and service lines which penetrate the shielded enclosure can be maintained from one location. This arrangement also makes things a little easier when maintaining the shielded enclosure since the most rapid degradation of the clamping hardware will typically occur on this wall. Obviously most of the stimulus for degradation will occur on this wall. If a shielded enclosure has degraded, this wall and the floor adjacent to this wall will be the first place to look for trouble. Meanwhile the three remaining walls and ceiling (if free of penetrations) will degrade at about the expected rate.

Typical Failure Modes

Once the location of the RF leakage has been identified by using appropriate testing techniques, the cause of the leakage must be determined. This search will require removal of selected enclosure components for inspection. The vast majority of leakage with clamping hardware occurs when the hardware is no longer clamped tightly, thus allowing oxidation of the hardware and mating surfaces to reduce conductivity at the clamped seam. In most of these cases the hardware was clearly tight at the time of assembly, the evidence for this being slight distortion of the flat clamp strip and the condition of the screw heads. With aging, the clamped seam compression apparently relaxed. Possibly this loosening was due to thickness changes in the core material rendering a clamped seam vulnerable to oxidation. There are cases where the same situation occurs but without indications that clamping hardware had been tight at the time of assembly. If one can loosen the screws easily by hand, it indicates an area where the installer positioned the hardware and skipped over a few screws when securing them at the required torque. When this occurs, it typically involves either a single screw or an entire row of screws. If one screw is loose, check the others associated with that particular clamp section to be sure that no others are loose. A third troublesome situation occurs when the installer applies so much torque to the screws that the flat portion of the clamping hardware becomes distorted. If the distortion is severe enough, the clamping hardware may not form an effective RF seam.

Corrective Action

The first two situations described above can be corrected by removing the offending clamps, cleaning all of the mating surfaces, and reinstalling the clamps. In the third situation one needs to obtain a new flat clamp from the enclosure manufacturer. Gentle cleaning should be performed to remove the oxides present on the mating surfaces. Clamping hardware is typically finished with zinc electroplate. The surfaces of the shielded panel may be finished with galvanizing or zinc electroplate. Aged surfaces will appear dull and may give the impression of a fine white powder adhering to the surface. Figure 2 is an example of slight to moderate oxidation of the flat strip mating surfaces.

After cleaning, the surfaces will have a slight sheen and there will be no traces of the white powder. The shielded panel surfaces will remain fairly dark. Inspection with a flashlight held at an angle to the surface will determine how effective the cleaning efforts have been. The clamping hardware usually will take on a noticeable sheen when it is clean, since electroplate cleans up more easily than the galvanization found on the shielded panels. Never use a cleaning process that will remove the plating from the clamping hardware or the galvanizing from the shielded panels. This removal would leave bare steel mating surfaces and consequent corrosion problems. Once the mating surfaces have been cleaned, avoid touching the surfaces with bare hands. Skin oils can accelerate the corrosion process so handle clean surfaces with care. Figure 1 is an example of an aged seam that has been restored to meet the manufacturer's original specifications after approximately 3.5 years of service in a humid environment.

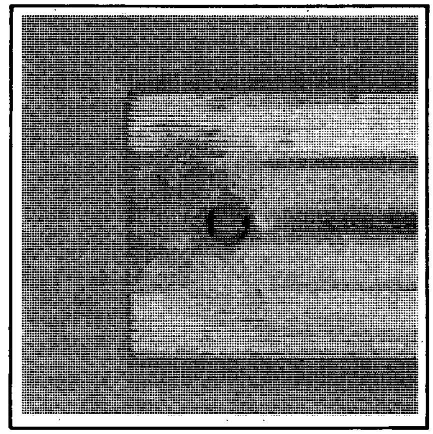

Figure 2. Slight to Moderate Oxidation of Flat Strip Mating Surfaces.

Screws

The high torque settings required to secure the clamping hardware can cause damage to the screw heads. Damaged screws should be replaced with new screws tightened with the amount of torque specified by the enclosure manufacturer. This replacement is best accomplished using an electric screw gun with an adjustable clutch for setting the torque. Do not yield to the temptation to overtighten the screws. Most good quality screw guns can deliver about 120 inch pounds of torque and that is sufficient to snap the heads off of the screws and/or strip the threads in the clamping hardware. Figure 3 shows two screw heads that have been damaged by the use of excessive force. The flat strip portion of the clamping hardware can distort to the point where gaps will open between the clamp surface and the shielded panel surface. If the threads in the clamping hardware are stripped, the hole must be drilled out and tapped for the next larger screw size. Keep some screws of this size on hand along with the correct drill bit and tap since stripping of screws occurs even with new hardware. Some installers simply insert a longer screw in the existing hole and thread a nut on the opposite side of the enclosure. This is possible with some styles of hat hardware but not well advised. Areas where this has been done are prone to leakage after only slight aging. This rapid leakage makes sense when one considers that a stripped hole has a larger diameter than originally intended and does not contact the screw body so as to form an effective RF field.

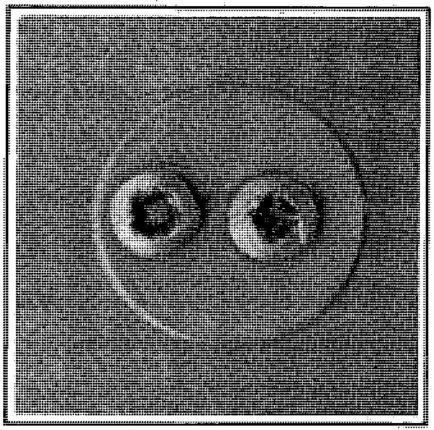

Figure 3. Screw Heads Damaged by Excessive Force.

RF SHIELDED DOORS

General Comments

No one subject about shielded enclosures stirs up as much controversy as that of shielded enclosure doors. Problems with doors plague both manufacturers and users. Both groups must share the blame for the considerable dissatisfaction with shielded enclosure doors. The manufacturers have not been awfully creative with their designs in the last fifteen years, but the user community continues to insist on buying decibels of shielding effectiveness over ranges of frequencies which may very well not be needed and which require added door weight and complexity. Although there is a lot of room for improvement on the part of both the manufacturers and the users, this article addresses how to deal with the problems of the existing situation.

The two most common types of doors for modular shielded enclosures are the knife edge type doors where the fingerstock is mounted in a receiver channel on the door frame, and the flat mating surface type doors which have the fingerstock mounted on the mating surface of the door leaf. There are other variations in door sealing hardware using mesh gasket and the like, but these configurations are not within the scope of this article.

The premier rule of door repair is to follow the manufacturer's instructions for maintaining the door so as to avoid frequent repairs. Instruct users in how to operate the doors without slamming the hardware, how to protect the threshold, how to avoid becoming entangled in fingerstock, and most importantly, how to avoid personal injury. Doors can be repaired with basic hand tools; people are much more difficult to repair. Check the operation of doors frequently and watch for the accumulation of dirt and foreign objects.

Failure Modes and Symptoms

A shielded enclosure door will provide attenuation in accordance with the more stringent national standards only when it is clean. As a rule, magnetic field attenuation in the low frequency range will degrade with the onset of corrosion, and this problem reoccurs in only a matter of days after cleaning if you are a user located in an extreme environment. This will be followed by degradation of the highest frequency plane wave attenuation capability although this takes a while to occur. It is suprising how dirty a door can be and still provide plane wave attenuation, particularly in the case of knife edge style doors.

Most users are not aware that the shielding effectiveness of a door is degrading until the degradation of the door is pretty far along. When a user is making measurements within a shielded enclosure in accordance with MIL-STD-461 limits, or FCC Class A and B limits, the first performance degradation indication will be an objectionable rise in the enclosure ambient. Usually, not too much attention is paid to this rise until sharp narrowband signals start appearing in the test data that stand out from the broadband noise. Panic sets in as these signals approach the measurement specification limits. These signals are typically caused by nearby radio and TV broadcasts.

Simple observation of facility users can provide clues to the status of a door. Most of the high performance doors on the market today are not easy to open or close even when they are correctly adjusted. If the contact fingers become dirty, or if the door alignment shifts slightly, the door will become even more difficult to operate. This difficulty causes an exponential increase in user irritation; and the users will be more blatant about slamming the door, leaning on the handle, and applying colorful verbal metaphor, particularly if there is anyone remotely related to the maintenance of shielded enclosures within earshot. When these symptoms start to appear in the users, a quick visual inspection of the door will usually reveal the cause of the problem.

Before opening the door for inspection, take a moment to survey the surroundings. Is the floor near the door clean and free of dirt and small objects that could become lodged in the door? Are any of the small objects lying on the floor parts that may have once belonged to the door? Are pieces of fingerstock scattered around? The little bits and pieces found lying about are telling evidence about the condition of the door. Examine the hinges to see if the gap on adjustable hinges is reasonably set in the vertical direction or if the adjustments have been run out to the maximum. Look for a telltale pile of filings on the lower hinge upper surface or the floor under the lower hinge which would indicate excessive hinge binding and wear of hinge components. Figure 4 is an example of a hinge with surface markings that indicate binding. Some doors do not have adjustable hinges. In this case look for an unusual arrangement of shim stock behind the hinges as an indication that something is amiss. Hinges should look straight and be free of mechanical distortion. Hinges that do not look straight are an indication that something is not right with the door. Check the handle to be sure that excessive play is not present.

In subsequent observations there will be a need to differentiate between door types to prevent confusion. Each type of door has its own maintenance peculiarities.

Flat Mating Surface Door

This style of door is the simplest door from a conceptual point of view and is fairly easy to maintain. Fingerstock is typically adhesive-backed and attached to the door leaf. The door leaf is finished with a conductive surface against which the fingerstock compresses and contacts when the door leaf is pressed against the conductive finish of the door frame. Note that the adhesive backing of the fingerstock does not have to be conductive for this to work but the surfaces against which the fingerstock wipe must be clean and very conductive. For these surfaces to be conductive, plated surfaces are provided by the manufacturer on both the door frame and the door leaf. Do not use any process for cleaning these surfaces that might remove the plating or reduce the surface conductivity. If the plating is damaged, consult the manufacturer for repair instructions.

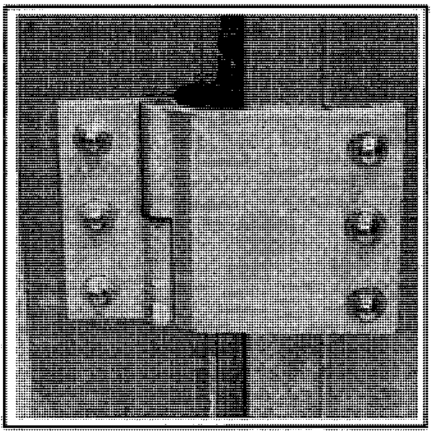

Figure 4. Hinge with Surface Markings Indicating Binding.

In cases where fingerstock has been damaged, try to determine the cause of damage before repairing the fingers. Fingers that have been damaged by contact with foreign objects such as equipment carts, clothing, or other objects, can be replaced without much concern. Fingers that fail repeatedly in one location such as near a hinge or near a latch may be subject to excessive compression and will most likely fail again. In this case, examine the overall mechanics of the door and implement some corrective action to the door itself to restore proper operation. This process may involve adjusting shim stock behind the hinges or at the latch points. Remember that any adjustment made to this type of door that influences fingerstock contact pressure will have some influence on shielding effectiveness. Also, be sure to examine the door leaf for evidence of warpage. Most doors have a wood core that will warp under adverse environmental conditions. In this case, consult the manufacturer.

Fingerstock replacement is not difficult with this type of door. Use care when removing the damaged original fingerstock so as not to cause any further damage. Be sure to remove any traces of the adhesive material if there is any residue on the door frame, but use care so as not to damage the plating. Replace the damaged fingers with new fingerstock strips as recommended by the manufacturer. Make sure that the replacement strips have the finish which the manufacturer recommends; do not accept a substitute. Also, be advised that some manufacturers offer fingerstock in a snag free configuration. This fingerstock is less susceptible to damage by accidental contact, but it may not provide the same long term electrical performance that conventional designs provide in many door applications. It is always best to consult the manufacturer or a consultant if there is any doubt as to which materials are best suited for a particular application.

Knife Edge Door

This style of door has been around for many years and has a proven record for performance when properly maintained. The design is more complex than the design for the flat surface door, and adjustment and maintenance of this style door is commensurately more difficult. Fingerstock is held in place in a recessed conductive channel in the door frame and the door leaf frame is banded by a conductive extrusion forming a knife edge. The knife edge penetrates the door frame recess on closure, with the fingerstock contacting both the side of the knife edge and the door frame recess. The door frame extrusion and door leaf extrusion are made of brass or bronze and are highly conductive. They are not plated surfaces so they can withstand considerable surface erosion without the need for replacement or refinishing. Two rows of fingerstock are typically installed in the channel extrusion recess, but there are variations. At least one vendor places a knitted wire mesh over a foam rubber core gasket in the recess, and another vendor is known for a twin knife edge variation with four rows of fingerstock held in the door frame. In some variations the fingerstock is held in place by the shape of the extrusion while other variations depend on adhesive-backed fingerstock for contact retention.

In cases where the fingerstock has been damaged, try to determine the cause of the damage before repairing the fingers. The recessed position of the fingers is a great advantage with this style of door since the fingers are much less susceptible to damage by accidental contact than their counterparts on a flat surface door. If a random broken finger is found, repair is straightforward. Follow the manufacturers suggested procedure for cutting a length of fingerstock from replacement stock and slide the replacement part into the recess under the damaged area. Make sure that the remains of the original damaged finger are clear of the channel otherwise further damage may occur. In a situation where a row of fingers are damaged, the door leaf may not be properly aligned with the frame. The knife edge style doors are quite tolerant of warpage in the leaf but cannot tolerate the slightest error in alignment in either the vertical or horizontal directions due to the tight dimensional tolerances required by the design. The high performance of the knife edge type door configuration does have its price.

Examine the door leaf with respect to the frame to determine if they are square with each other. Slipping of the bolts that penetrate the leaf at the hinges can cause the door to sag on the latch side. Thus the door leaf may appear to be rotated slightly with respect to the frame and damage to the fingerstock in the upper and lower recesses on the latch side of the door may be evident. Fingerstock damaged by this condition is shown in Figure 5A. This situation can be corrected by judicious manipulation of the hinge hardware. The major manufacturers supply adjustable hinges which facilitate this operation. Also look for cases where the knife edge penetrates the recess from too high or too low a position on door closure. This misalignment can cause shearing off of the fingers in large segments in the upper and lower recesses. Typical fingerstock damage for this condition is shown in Figure 5B. Adjustment screws are provided by some manufacturers which act against the hinge pins to set the vertical position of the door. Use a small mirror to view the knife edge as it penetrates the recess while making this adjustment.

Adjustments in the horizontal direction are the most difficult to perform and are critical with respect to fingerstock life. The manufacturers supply hinges that position the door leaf very close to the hinge's center of rotation. The knife edge, if it is of any practical length, enters the frame recess at a very sharp angle on the hinge side of the door. This leaves almost no room for error in the horizontal door adjustment. If the knife edge enters the recess too close to the outer edge of the recess, the knife edge may scrape against and drag on the outer edge of the recess. On full closure the knife edge may exert excessive force on the outer row of fingers on the hinge side of the door and the inner row of fingers on the latch side of the door. The result will be failed fingerstock in the locations mentioned. On the other hand, if the knife edge enters the recess too close to the inner row of fingers on the hinge side, a loud popping of the fingerstock will be heard on closure of the door. This is caused by the inner row of fingerstock on the hinge side of the door compression back into the recess on initial contact with the knife edge and then suddenly relaxing under compression into the correct position on closure. This condition also seems to degrade fingerstock life. Test for this condition by stiffly pushing the door closed from the wide open position and releasing it prior to knife edge penetration on the hinge side. If the door leaf bounces back toward you without the knife-edge engagement, problems exist. If the knife edge penetrates partially into the recess, the alignment is more nearly correct. The alignment procedure takes a lot of practice to master and is best left to a manufacturer's representative or a skilled consultant. When a knife edge door is correctly adjusted in the horizontal direction, it may appear to be skewed slightly to the hinge side of the door. This appearance should not be a cause for concern if the door is operating smoothly.

Inspection of the mating of the knife edge with the recess may reveal that the frame is warped in the vertical or horizontal direction, and an unusual damage pattern in the fingerstock may confirm that this is the case. This happens from time to time particularly with large frames such as double door frames. This problem can be corrected in the field in many cases and requires loosening the door frame from the shielded enclosure. The frames are suprisingly flexible and can be restored to their original configuration if manipulated carefully. This process should not be attempted without the aid of an experienced consultant or a manufacturer's representative. One can proceed with fingerstock replacement after the frame and latching mechanism have been restored to good working order.

Fingerstock replacement is quite a bit more difficult on a knife edge style door than on a flat surface door. The correct technique must be developed. Remove the existing fingerstock as efficiently as possible; there is really no graceful way to do this. The second row comes out a lot easier than the first. Remove the knitted wire mesh over the foam rubber gasket, if present. Clean the knife edge and entire depth of the channel to remove all dark corrosion deposits, oil, and residual adhesive. Pay particular attention to the locations where the fingers contact the recess surfaces with a wiping action as this is where attention to detail pays off. Contact the manufacturer for suggested materials for cleaning these surfaces; do not even think about using harsh abrasives. It seems that no matter how much effort is applied to cleaning these surfaces, one more pass with a solvent soaked rag will reveal dirt. As a rule, quit when the recess and knife edge look clean and shiny.

Many users achieve good results using fingerstock procured in roll form, but use fingerstock of the type recommended by the door manufacturer and be sure that the fingerstock received is provided with the finish

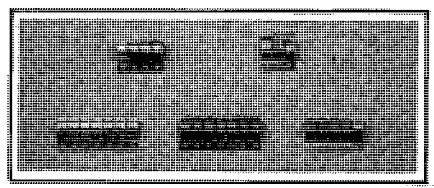

Figure 5A. Fingerstock Damaged by Slipping Hinge Hardware.

Figure 5B. Fingerstock Shirring Caused by Poor Knife-edge Alignment.

recommended by the manufacturer. Do not accept a substitute. Install the fingers in accordance with the manufacturer's instructions. The first row of fingerstock will go in easily; the second row will not. Proceed slowly so as not to damage the first row while installing the second. This is necessarily a time-consuming, tedious process. The most difficult aspect of the entire job is replacing the knitted wire mesh over the foam rubber gasket. Figure 6 is an example of a gasket which has degraded over time. The new gasket is worked into place after the fingerstock is in place and must be placed carefully to avoid damaging the new fingers. Not all manufacturers use this material so some users may never have the opportunity to experience this delightful chore. An experienced individual can perform this task many times without breaking a single finger. In the case where a finger is broken, the manufacturer's procedure for slipping a short row of fingers under the existing fingerstock at the point of the defect is an acceptable practice.

Once the fingerstock has been replaced, the door can be closed. Do this very slowly and listen for any binding or crunching. If the door was properly adjusted prior to replacing the fingerstock, all should be well. Otherwise the user may be in a position to damage all of the corrective work just performed. Use a spray lubricant in accordance with the door manufacturer's instructions after checking and verifying that the knife edge is engaging the recess correctly. However, do not overapply the lubricant as old lubricant will tend to trap particles of dust and dirt within the recess.

Latching Mechanism

The following comments apply to both types of door configurations. Care must be taken to assure that the latch mechanisms operate correctly. There are so many variations on the mechanisms used that they cannot be covered within the scope of this paper. An item of concern is always the door handle shaft penetration. These assemblies can be removed and cleaned when identified as the source of RF leakage. It is best to replace any gaskets removed from the handle with a new gasket; but in many cases, the compressed wire mesh gaskets found on some door handle hardware can be reused if they are clean. Be sure that the reassembled handle rotates smoothly and is free of play. Any play or binding will lead to accelerated degradation of the handle shaft and bearing surfaces. A worn handle shaft is shown in Figure 7.

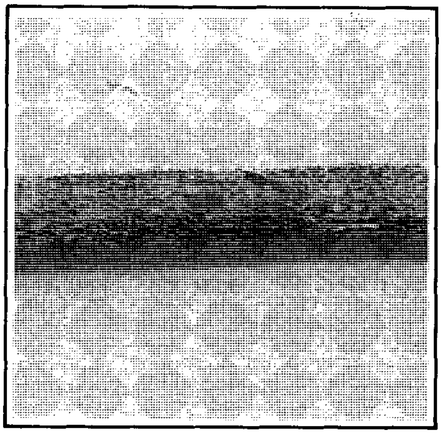

Figure 6. Degraded Gasket.

Inspect the cam rollers and latch bar mechanism for loose, worn, or cracked parts. These components are heavily stressed and weld failures are not uncommon. A failure of these components can lead to an individual being trapped within a shielded enclosure. This happens far too often, and it is not an acceptable condition at any time. Replace any suspect components promptly before there is a chance of an accident.

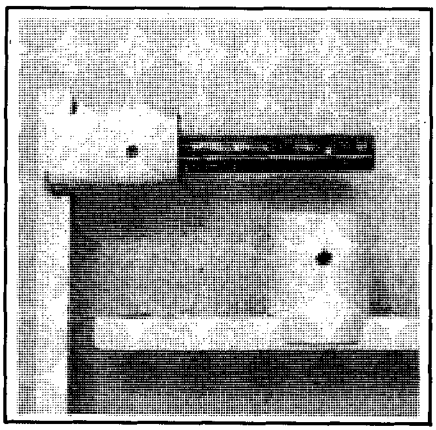

Figure 7. Worn Handle Shaft.

HONEYCOMB VENTILATION PANELS

General Comments

Honeycomb ventilation panels seem to be one of the most likely places to look when there is trouble in a shielded enclosure. Problems with these panels are probably second only to door degradation in terms of frequency of occurence. The severity of the problem is a function of how the honeycomb material is configured and how the honeycomb is used. How the honeycomb is used may seem to be an unusual comment since it is generally understood that honeycomb ventilation panels are used to allow passage of air without passage of RF fields. It turns out that the temperature and the relative humidity of the air flowing through the honeycomb ventilation panels determines, to a large extent, how the panel will degrade over time. This observation means that the troubles a user encounters will result from the honeycomb ventilation panel application such as supply air, return air, pressure relief, or lightning heat exhaust. In each case air velocity, temperature, and humidity are quite different.

Honeycomb Configuration

Different manufacturers have different techniques for securing the honeycomb material in place. Each of the different techniques fails in a different manner over a period of time, and some techniques seem to be much more tolerant of environmental effects than others.

As an example, one manufacturer clamps the raw honeycomb into a frame fabricated from standard *hat* and *flat* stock that has been welded into the desired shape and then plated. The honeycomb material effectively bites into the frame when the frame is secured to the host shield to form the honeycomb/frame RF seal. The frame is clamped to the RF panels just like any other panel would be with the exception that gasket is used (typically knitted wire mesh rope gasket) apparently to make up for dimensional differences between the completed honeycomb frame and the shielded panels and to provide the RF seal. Another vendor eliminates the need for a frame by soldering the honeycomb stock directly into a cutout in a laminated panel. The panel is typically made in a convenient dimension so that it can be bolted into place just like any other panel. Other vendors have used different techniques for securing honeycomb in place, but the two methods described are the ones most frequently encountered in work with modular shielded enclosures.

Typical Failure Modes and Corrective Action

Each honeycomb panel configuration has its own failure modes, but the application of the panel will determine how quickly and how severely the panel degrades. Local environmental conditions play a major role in determining where degradation will first appear. Usually honeycomb panels which degrade first on any given shielded facility are the supply air panels. In most shielded facilities an air handler unit forces cold supply air into the shielded portion of the facility via ductwork leading to a honeycomb ventilation penetration at the shielded surface. Dielectric vibration isolators isolate the ductwork electrically and prevent vibrations from the air handler unit from vibrating the shielded enclosure surface and penetrating hardware at this point. This supply air is frequently chilled to a very low temperature in contrast to the ambient air so as to provide cooling for equipment that may be operating within the shielded enclosure. Typically the space under a raised floor within the shielded enclosure is used as a plenum for distribution of chilled air. This air is heated by operating equipment within the shielded enclosure and returns through the open space of the enclosure interior to the air handler unit via return air ducts and a larger honeycomb ventilation panel, or sometimes via several honeycomb ventilation panels scattered over the enclosure surface.

In some facilities the supply air chills the supply ductwork and honeycomb ventilation panels to a temperature below the dew point. Moisture in the local environment can condense on these surfaces and corrosion now has the opportunity to strike. The honeycomb core material itself will rust, but it is suprising how rusted the core can appear before the core material itself fails. The first failure will most likely occur at the point where the honeycomb core mates with the frame, if a frame is used, and then at the point where the frame mates with the shielded enclosure surface. In cases where no frame is used, failures are frequently observed at the seams where the panel containing the honeycomb joins the other panels forming the enclosure surface. The honeycomb ventilation panels that are soldered into place without a frame are less susceptible to the short term failures observed in framed honeycomb panels in cases where condensation occurs.

It has been speculated that the actual honeycomb core would rust through and fail with no preferential failure rate for either of the honeycomb configurations described. However in actual use, the frame and clamping hardware appear to fail long before the core can rust through. Look for exceptions to this rule to occur where moisture is dripping directly on the core material or where the air flowing through the vent is contaminated with corrosives.

Figure 8 is a photograph of a honeycomb ventilation panel frame that has been in service continuously in a high humidity environment for about four years. This frame was part of the supply air duct and shows considerable evidence of condensation induced rust. Note the high concentration of rust near the frame corners. The highest stress concentrations are frequently at these locations since this is where an assembler may really *lean* on the screw gun to achieve a good RF seal. The honeycomb core material really bites into the frame at these points. Close examination of this photograph will reveal the honeycomb pattern pressed into the frame. The frame shown was responsible for considerable leakage in the room at the time testing was conducted - the kind of leakage that might be expected if someone left a door open. The rust shown is very deep, and the frame could not be restored easily to service. The piece shown was taken to an experienced plater. Acid etch and sandblasting were required before this piece could be replated with zinc electroplate. This work was performed for about one-third the cost of obtaining new replacement material from a vendor. The real advantage in this case was that a well-equipped plating house provided one day service for this hardware repair. A manufacturer may not have honeycomb to fit your application in stock at all times. This is an important consideration in preparing a service schedule.

In stark contrast, the return air duct honeycomb ventilation panel located only a few feet away required only the usual frame and mating surface cleaning for restoration to specifications. The honeycomb core material was quite rusted, but the frame was about as would be expected for any panel/frame seam after four years of use in a humid environment. Failures were as would be expected given the expansion, contraction, and moisture absorption problems associated with modular shielded enclosures. In a situation where the hardware is still in good shape, the procedures for restoring clamping hardware may correct the problem.

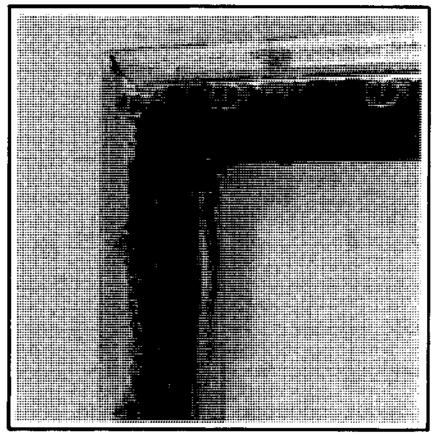

Figure 8. Honeycomb Ventilation Panel after Long-term Use in a High Humidity Environment.

Air velocity may play some role in the degradation process. There is typically quite a bit of vibration present at the supply air duct interface even with dielectric vibration isolators installed to isolate vibrations from the air handler unit. One can feel this vibration when touching the shielded surfaces near the penetration, or the honeycomb material itself during periods when the air handler is in operation. There is no doubt a greater transient stress applied when the air handler unit is cycled on and off. The evidence for a vibration induced failure is not as obvious as the condensation induced failure where physical evidence is available for inspection. Often the supply air penetrations, regardless of the honeycomb configuration, fail more severely than their return air counterparts. No serious corrosion is observed in these cases. If the plated surfaces are intact, the corrective action is the same as would be expected for any degraded panel/clamp seam.

CORNER HARDWARE

General Comments

There is plenty of opportunity for difficulties at any location where three RF shielded planes intersect. Every manufacturer of modular shielded enclosures has some nifty approach for providing an RF seal, and some of these approaches degrade spectacularly when exposed to an adverse environment. The requirement for modularity and the need to assemble and disassemble the enclosure conveniently are probably the causes of a lot of the problems suffered at corner intersections. Manufacturers supply a variety of preformed corner clamping hardware to meet the modularity requirements for the various types of corners. Like any other shielding hardware, some of these hold up better than others against the test of time and environment.

Hardware Configuration

One manufacturer provides a welded and plated preformed corner assembly that consists of several inches of hat and flat hardware configured so that the corner hardware does not have leakage paths (seams) at the intersection point of the three shielded planes. In actual use this joint configuration is really no more susceptible to failure than any other panel/frame seam, and corrective action is as would be expected for such a seam. Another vendor has gone so far as to eliminate clamping at the corners by using a completely preformed three plane corner. Welding and soldering of the corner piece is performed at the factory, and the entire corner section is bolted into place on site. Like the other corner hardware, there are no leakage paths at the intersection point of the three shielded planes. The authors have not had any experience with this configuration in terms of failure history so unique failure modes have not yet been identified.

Another manufacturer offers a preformed bronze or brass casting that acts as a corner cap. This cap consists of a fitting inside the enclosure at the intersection of the three shielded planes with the larger cap portion covering the intersection on the exterior surface. The cap is clamped into place by a single screw penetrating the two pieces. The cap casting is not very large and this means that there are RF leakage paths very close to the intersection point of the three shielded planes. Additionally, the cap casting is very rigid so it cannot conform to any perturbations in the shielded surfaces near the intersection point. This rigidity means that the corner cap is a bit tricky to install correctly. Many of these corners in aged facilities reveal numerous markings left by the installers indicating that repeated testing and adjustment was required during installation to achieve the required RF seal.

Corrective Action

The caps are easily cleaned and can be replaced using the same procedure used by the manufacturer during routine shielded enclosure maintenance. Be sure to remove old material that may be behind the caps and replace it with shiny new material of the same grade. If the enclosure is a permanent one which is not destined to be relocated or modified, consider a more permanent approach to installing the corner caps. The corner caps located at floor level seem to degrade before their counterparts at ceiling level. Examination often reveals that the caps at floor level exhibit more advanced corrosion than caps at ceiling level, all other things being equal. Caps removed from facilities which have underfloor forced air cooling usually display this problem, and it is felt that condensation may play a role in the accelerated degradation. In a recently examined facility which had had two years of continuous operation in a humid environment, the ceiling level corner caps were performing as would be expected while the corner caps at floor level had all suffered significantly accelerated degradation.

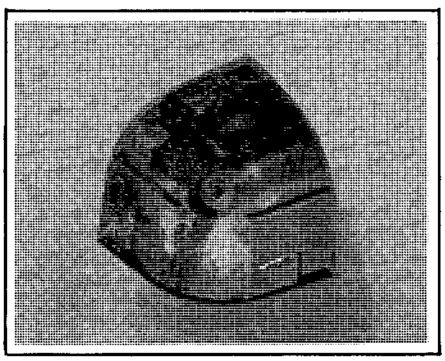

Figure 9. Corner Cap after Exposure to Excess Moisture.

Figure 9 shows a corner cap which has been exposed to excess moisture. Discoloration is quite evident and corrosion products cover the surfaces which would mate with the shielded panels. While this is a severe example, the cap shown could be cleaned and used again without any great difficulty, provided that all of the other surfaces at the intersection were serviceable.

Vestibule Corner Hardware

The inside corners of a vestibule have always been a sore point with every user of shielded enclosures who has encountered RF leakage problems. Many vestibule designs are not implemented with preformed hardware since customer selected dimensions do not always permit this. The result is that the manufacturer is sometimes forced to field fabricate a corner (not good practice), or use a contrived configuration of hat and flat hardware to create an RF seal at the intersection point of the three surfaces. When looking for trouble near a vestibule door, the inside intersections are a likely place to find it. These corners seem particularly susceptible to failure since the manufacturer's design/implementation is typically marginal, and the corners are invariably located near a door which induces shock and vibration in the hardware.

One often suffers considerable frustration in attempting repair of this type of corner. Typically quite a length of interior and exterior frame material needs to be removed to gain access to the appropriate surfaces for cleaning. Since these corners are not always fashioned out of standard preformed components, there are frequently *surprise* hardware implementations to be dealt with. Original foil and other material found in the seams should be removed and discarded, and the surfaces cleaned as usual. Carefully replace the materials found in the seams with bright clean new materials of the same grade, and then assemble the hardware in its original configuration. Be prepared to do this a couple of times for this type of corner; they are tricky and the repair effort may require a few iterations before satisfactory test results are obtained. If the shielded enclosure is not destined for relocation or modification, consider a more permanent correction for this type of corner.

FILTERS

Filter Configuration

Filters are an item which typically do not need much repair, but there are a few problems which are worthy of noting. The typical filter is attached to the surface of a shielded enclosure by a threaded conduit that is RF bonded to the filter case and sometimes supported by additional mounting lugs in the case of large power filters. The threaded conduit penetrates the shielded enclosure surface, and threaded fittings or an assortment of locknuts and washers are used on the enclosure surface opposite the filter cabinet to secure the filter cabinet in place. The RF seal between the enclosure surface and the filter cabinet is formed when the threaded fittings compress the shielded surface as the fittings are tightened. Some vendors use RF gasket material to enhance the RF properties of this configuration by placing the gasket material behind the filter cabinet, between the shielded surface and the threaded fitting, or in both locations. Some vendors do not use gasket material at all.

Typical Failure Modes

During the installation of the filter cabinet, the core material of the shielded panel on which the filter cabinet is mounted is compressed. This compression is to be expected; otherwise it would not be nearly as easy as it is to achieve a good tight RF seal. After a period of time, environmental effects can cause this tight fit to relax; and before long problems occur. The cumulative effects of temperature variation, moisture absorption and vibration can lead to a filter which is actually loose to the touch. Electrical contact will diminish as oxidation sets in, and the result is an RF leak. This is a serious leak because leads attached to the filter on both the input and output sides of the filter will act as wire antennas and will couple all kinds of signals into what may have once been a low level ambient.

Corrective Action

Fortunately, these problems are easy to find and easy to correct. Removal and cleaning of the offending hardware, replacement of the gasket material, and careful hardware reassembly will usually restore even the worst offenders to acceptable performance. Be sure to check the mounting lugs for the filter cabinet if these are present. Be sure that all of the hardware is snug since loose hardware penetrating a shielded surface can cause RF leakage.

In the case of small filters where the load compartment is soldered to form a permanent RF seal, there really isn't anything else that is field repairable. If the load compartment is provided with a bolt-on cover, be sure to check and replace the gasket, if needed, taking care to assure that the mating surfaces are free of oxides. Knitted wire mesh gaskets take a set pretty quickly. Usually the existing gaskets are compressed from the original installation and are not all that serviceable after rework has been performed. Further tightening of the load compartment cover bolts to achieve an effective RF seal will often result in a distorted load compartment cover and the same amount of RF leakage as encountered prior to the rework.

Multiple Filter Cabinets

Some of the larger filters are packages of several individually sealed filter units installed in an RF cabinet. This situation is frequently found where several telephone or control filters are grouped together or in cases where multi-phase power line filters are grouped together. For maintenance purposes, the RF load compartment can be treated just like the load compartment of an individual filter as described previously. Usually the individual filters within the RF cabinet will also have an RF gasket which forms an RF seal between the load end of the filter and the RF cabinet load compartment bulkhead. These gaskets are typically knitted wire mesh and, more often than not, have been compressed to an extreme extent during the original installation. If for any reason one needs to replace an individual filter unit from within an RF cabinet, the gasket should be replaced after the requisite cleaning of all mating surfaces. The temptation to tighten the filter mounting bolts may be great, but the end result will eventually be a distorted load compartment bulkhead and possibly broken mounting studs on the individual filter unit.

An interesting note is that the threaded conduit attached to the filter or to the filter cabinet RF load compartment is referred to as a waveguide fitting in many DOD and commercial procurement specifications. This could not be more misleading. Any time that a filter is in use it has wires connected to it, and these wires are routed through the threaded conduit. Once conductive material like insulated wire is routed through a conduit, waveguide boundary conditions have to be replaced with transmission line boundary conditions. This situation means that the threaded fitting will behave like a transmission line under actual use. When performing tests to verify the performance of a reworked filter installation, be sure that all of the wires originally connected to the filter are in place. If the wires are not in place, the threaded fitting will act like a waveguide; and the test performed may provide some misleading results. A filter cabinet can be full of holes and still not appear to be degraded during testing if there are no leads routed from the load compartment through the threaded fitting and into the shielded enclosure.

Electrical Overstress

There are cases where the filtered circuit is functioning from an operational perspective; but for some reason, RF leakage continues to appear to emanate from the filter no matter how carefully installed. In this case the components within the filter may have been damaged by electrical overstress. This damage can be caused by transient voltages or currents that have exceeded the filter component's ratings. Expect this kind of thing to show up in telephone, signal and control line filters which are used in an environment where lightning induced transients may be present. Usually when a filter component fails, the circuit using the filter will cease to function correctly. There are cases (open capacitors in pi filters) where the circuit continues to function, but the filter is not acting as an effective RF attenuator. One can test a filter's attenuation performance using the procedures of MIL-STD-220. This is a time-consuming process requiring the removal of the filter and a lot of test equipment. If the suspect filter is a relatively inexpensive one, replacement is probably the most efficient and cost-effective option.

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MISCELLANEOUS PENETRATIONS

There are many minor penetrations in most shielded installations and these may cause problems from time to time. For example, there are small waveguides for fiber optic cables, penetration plates for instrumentation, structural bolts for supporting hardware, ground studs, fire protection sprinklers, and all the other things that make a facility work. A lot of the corrective procedures which apply to clamping hardware can be applied to penetration hardware. When penetration hardware fails, disassemble the hardware for inspection and perform corrective action. Clean all mating surfaces on the hardware and the shielded panel taking care not to remove the plating on the surfaces. If the original cutout for the penetration was oversized by the installer, all kinds of copper foil and copper wool may have been stuffed into the penetration. In this case, obtain new clean material and reassemble the penetration. Also it is a good idea to replace any gasket material with new material.

If a new hole must be drilled in an enclosure panel, it must be drilled as perpendicular to the plane of the panel as possible. Consequently, when hardware is installed through the hole, the mating surfaces will seal flat against the panel forming a uniform RF seal around the hardware perimeter. If the hole is drilled at an angle, the hardware will not seal flat and the uniform perimeter sealing action will not occur. This technique is particularly important in the case where large bolts such as filter cabinet lugs or ground studs penetrate the shielded enclosure.

PREVENTIVE MAINTENANCE

Implementation of a regularly scheduled maintenance program is an excellent way to keep all of the little details of shielded enclosure maintenance in check before they can turn into the big headaches which are so often associated with aged shielded enclosures. This is not a new concept as the leading manufacturers have been supplying users with door maintenance kits for years. Here is a list of some things which can be done periodically to keep a shielded enclosure in good condition:

- Clean the RF shielded door at least monthly using the materials and procedures recommended by the manufacturer. Keeping a knife edge style door clean will make it easier to open and close, reducing the strain on both the latching mechanism and the operator. This routine will increase the life of the door hardware directly, and indirectly increase the life of the frame hardware by reducing shock induced by operators' slamming the door. Keeping the frame clean on a flat mating surface door will help maintain shielding effectiveness.
- Make minor hinge adjustments on an as-needed basis. Knife edge doors with only two hinges are notorious for slipping out of alignment.
- Check to see that the door area is clear of debris which might become trapped in the door hardware.
- Mingle with the users and drop by for facility visits whenever possible. Let them know that help is available, and encourage them to report problems.
- Post a sign on the door with all of the shielded enclosure dos and don'ts and put a maintenance name and phone number on it. Let the users know that there is a central location where problems can be reported. A sample sign from an actual facility is shown in Figure 10.
- Be sure that all cleaning personnel are warned about the possibility of damage to the enclosure if a water spill were to occur. Prepare a set of cleaning instructions and make sure the cleaning personnel understand why this room is different from the others.
- Maintain an inventory of spare fingerstock, gasket, screws and critical door components. If something needs to be done in a hurry, it is most efficient to have long lead time items on hand.
- Check for signs of condensation forming on the hardware, particularly where chilled air penetrates the facility. Look for situations