Fundamentals of EDM Notch Specification

A NDT Guide for Eddy Current Testing

by

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If you find errors or have recommendations on what needs to be added/dropped/edited I would appreciate your input.

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Foreword

I wish to thank the people at diverse companies that have shared their knowledge and experiences in non-destructive testing with me over the last 45 years. Particularly the teams at UniWest, Foerster, GE, Pratt & Whitney, Rolls-Royce, IHI, MTU and many, many others.

Special thanks go to Paul Notch and John Mays of the EDM Team at UniWest, for reviewing this document and providing their comments and corrections.

My sincere thanks to all of you!

Please note that I am not an expert in EDM notching. The real work requires skill and lots of patience. EDM is still an art, and I am not skilled. But I have specified many notches in the past, or helped customers with notch specifications, and learned from the questions that EDM Teams have asked.
This document is my attempt to share much of this knowledge with you in the hope that it will make your interactions with EDM Teams easier.
Some of it you may agree with and some of it could raise the statement “but that’s not right”. In the latter case please send me an email.
In any case, do talk to the EDM Teams that do the actual work - it will save time and money.

1. Introduction

The intent of this guide is to describe what information you would need to provide to the manufacturer of an EDM notch in order for him to place it where you want it on a part that you will provide to him or that he will manufacture for you.
I will first provide some background on what EDM notches are used for, on how EDM notches are manufactured, the terminology used in this document, and then get into the details of specifying notches, including examples. The primary application I am targeting is the creation of reference standards for testing for flaws using the Eddy Current Testing Method.

2. Background

In order to detect cracks or flaws and establish an idea of their severity in diverse automotive, medical, aircraft or other metallic components we need to somehow relate the signals observed on an instrument screen to something that we know precisely.
This is why EDM notches, i.e. notches made by electro-discharge machining, are commonly used in eddy current (ET) or ultrasonic (UT) non-destructive testing as reference “flaws” and the part that has the EDM notch is called a “reference standard”.
Prior to an inspection one uses this standard to set up the parameters on an eddy current instrument, such as frequency, gain, signal rotation and filters. These values are then adjusted so that the EDM notch results in a signal response with a specific amplitude; this process is called calibration. During the subsequent inspection of a part we can then evaluate any signal response observed and classify the part as acceptable, i.e. no flaws, or rejectable, i.e. flaws are present, if the amplitude of a signal-response exceeds a certain pre-set amplitude limit relative to the calibration signal.

Reference standards are commonly called out in inspection procedures, and one can purchase these from various manufacturers such as UniWest. The following figures show some example standards.

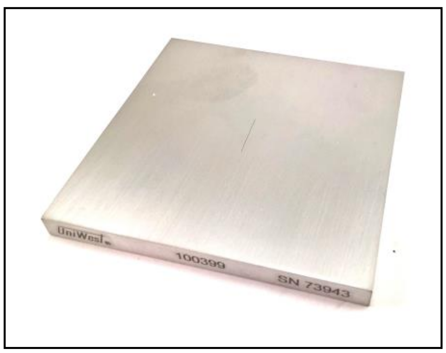

Fig. 2-1 Aluminum Standard with long notch

Fig. 2-2 Bolthole standard with holes of diverse diameters

Fig. 2-3 Bolthole standard with long axial notch on inner surface

EDM notches are also used for Probability of Detection analysis (POD), e.g. for flaw detectability determination on aircraft engine parts. In this case a large number of notches of different sizes at different locations is placed in one or two actual parts which are subsequently inspected with a specific instrument and sensor. The signal amplitudes are recorded as a function of EDM notch size and analyzed statistically. The results then tell us what size notch is detectable with a given certainty, and what we cannot reasonably detect. These numbers are then related to actual flaw sizes. POD results may be used to determine how often an in-service aircraft engine part needs to be inspected before it is retired from service.

3. The Manufacturing Process of EDM Notches

In order to understand what specifications for notches you should supply to an EDM Technician it might be helpful if I explain how EDM notches are created.
The concept behind EDM is quite simple. It is based on the same concept as the electrical spark that can happen on cold winter days when you are about to touch the handle of your car's door.
Except it's done at much higher voltages.
A high-voltage DC source is connected to a metal rod or wire (the tool) and the metal part that you want to be notched. The source generates a spark between the tool and the part, and a small amount of metal is burned away from both. Repeating this multiple times ends up creating a void in the part. The shape of the void or notch depends on the shape of the tool.

The two most common methods for creating notches are Wire EDM and Sinker EDM.

3.1 Wire EDM

Wire EDM uses a wire to create the notch. A spool of wire is mounted on a Wire EDM machine and connected to one electrode of the voltage source. The part itself is held in a basin filled with dielectric fluid and is connected to the other electrode of the source.
The machine then feeds the wire along the part and "sparks" it, causing a small amount of metal to be burned away from the part and the wire. To avoid using up the wire in the process, the wire is continuously spooled past the part as the part is moved towards the wire to create a deeper "burn". Wires are usually made from brass, copper alloys or tungsten alloys. The dielectric fluid is usually agitated and removes burn-residue from the notch.

What are the factors to consider when designing reference standards using Wire EDM?

First, the thickness of the wire. Normal wires for heavy cuts are 0.010 inches (0.25 mm) thick. This means the EDM notch ends up having a width of about 0.012-0.016 inches (0.30-0.41 mm) depending on how deep one wants the notch to be.
The smallest wire diameter available is 0.004 inch. Thin wires break easily so special care is needed during setup. Typical notch width ends up to be between 0.005 to 0.006 inches. One may have to cut a few standards in order to obtain one final, acceptable standard, which increases the cost significantly.

Second, the length of the notch. Since the wire is guided along the part it will cut across the whole side of the part that faces the wire. Also, Wire EDM only creates notches of even depth on flat surfaces if they are totally parallel to the wire. Wire EDM could be used, for example, to create a full-length long notch on the inner surface of a bolthole standard as shown in figure 3-1.
Tapered, or angled EDM notches can be created by tilting the surface of the standard relative to the wire. Common tapers have depths from 0.0 inches to 0.050 inches (fig.3-2).

Wire EDM is also often used to cut various parts into sections or segments.

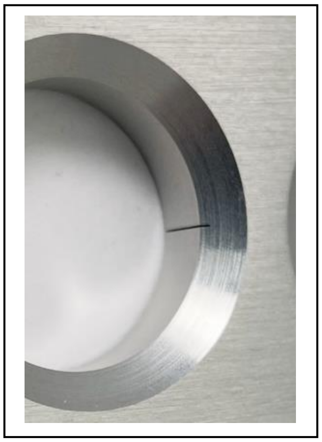

Fig. 3-1 Bolthole Standard

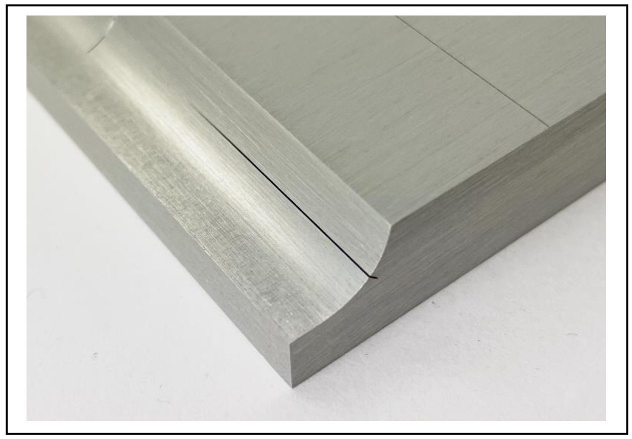

Fig. 3-2 Standard with tapered notch

3.2 Sinker EDM

Sinker EDM uses a specific tool, or “sinker” to cut the notch. Figure 3-3 displays various sinkers. A sinker (fig. 3-4) consists of a holder and an electrode mounted to its tip.

Fig. 3-3 Sinker tooling examples

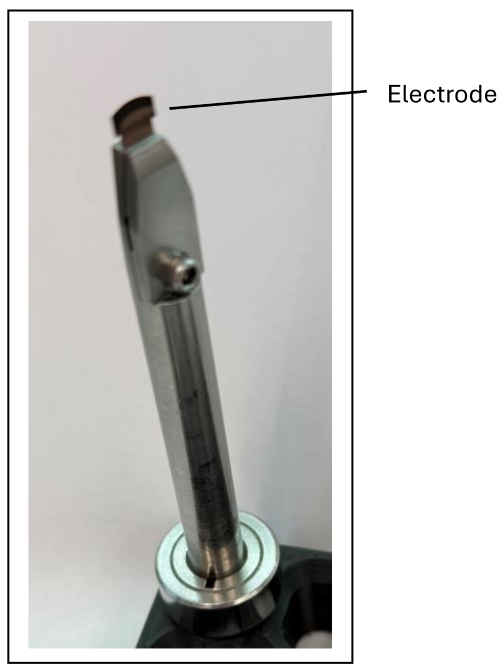

Fig. 3-4 Sinker with electrode

Electrodes are commonly made from tungsten or tungsten-copper alloys. They can be cut using a Wire EDM machine (fig. 3-5) and can be shaped as desired (figs. 3-6 and 3-7).

Fig. 3-5 Wire EDM machine

Fig. 3-6 Rectangular-shaped electrodes

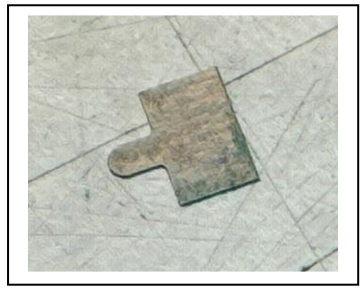

Fig. 3-7 Radius-shaped electrode

How does a Sinker EDM-machine work?

The electrode is mounted at the tip of the holder (fig. 3-4) and the holder is inserted into the EDM machine (fig. 3-8). The power source of the EDM machine is connected to the holder and to the part to be notched (fig. 3-9).

Once started, the machine plunges the holder up and down, sparking the part when down and flushing the notch with dielectric fluid when up. Machines of this type can move in 3D, allowing one to place notches at different angles.

Even though the machines are numerically controlled, they still require the experience and skill of an operator to properly form the electrodes, judge electrode-wear and place the notch in the desired location.

Fig. 3-8 Sinker EDM machine

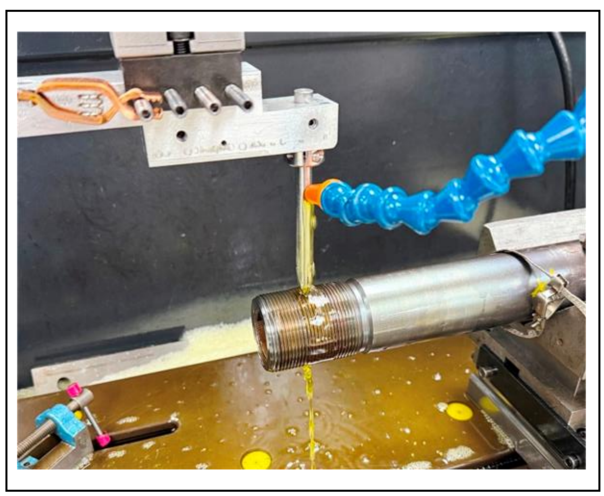

Fig. 3-9 Placing a notch in the root of a thread

To place a notch at a desired location I would need to know where you would like me to place it. To explain the process let's put a screw (fig. 3-10) into a wooden board 3.0 inches from the left and bottom edges. To do that I will need to measure these distances and then position the screw at the correct location.

Fig. 3-10 Screw to be placed into board

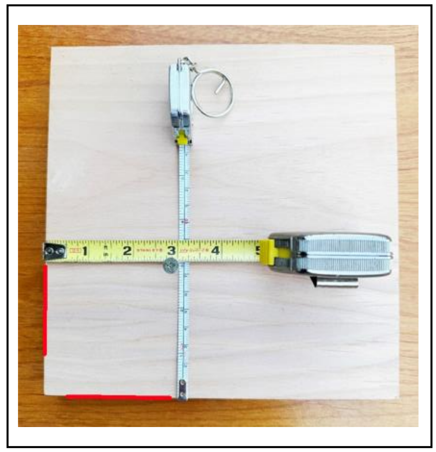

Fig. 3-11 Determining the location

To determine the position of the screw I need the distance (3.0 inches) and two edges (red lines in figure 3-11) as references from where to start measuring. The points where the two tape-measures contact the edges are called "touch-off points" or "touch-edges" in the world of machining and EDM notching.

Placing an EDM notch is done the same way. The technician manually guides the electrode close to a reference surface or edge ("touch-off point"). Once the electrode is sufficiently close, the machine can automatically drive it towards the edge until it almost touches. The position of the electrode is then stored in the machine's memory and corrected for the desired dimensions of the notch and the dimensions of the electrode. This step is repeated as necessary from additional touch-off points in order to define the exact location in 3D where the notch will be burned into the part. Depending on the complexity of the location the technician will perform a few additional steps and then program the depth of the burn. When the burn is completed, the part is removed and cleaned.

What are the factors to consider when designing reference standards using Sinker EDM?

First, the thickness of the electrode.
Normal electrodes are 0.0020 inches (0.051 mm) thick. This means the EDM notch ends up having a width of about 0.0025-0.0050 inches (0.064-0.13 mm) depending on how deep one wants the notch to be and the type of metal of the part. Typical final dimensions of widths are 0.003-0.005 inches depending on notch depth.
The length and depth depend on your specifications, the metal of the part and the tolerance of the dimensions of the electrode. Typically, lengths and depths of notches are within +/-0.002 inches (+/-0.05mm) of the specified dimensions.
Thinner electrode material made of tungsten is available in a thickness of 0.001 inches (0.025 mm) and would result in narrower EDM notches. However, the EDM process may result in bad notches: Thinner electrodes bend easily during the burning process and create extra-wide or deformed notches, which subsequently ruin the part. One may have to notch several parts or re-make standards to obtain one final, acceptable part. I.e. it can come at a higher cost and final price.

Second, the metal of the part to receive the notches.
With Sinker EDM one can make very long notches, over 2 inches or more in length, and very deep notches. However, burn-time and hence cost can vary depending on the metal of the part. Aluminum burns fast and relatively easy. Titanium, Inconel and hardened steel alloys take longer to notch.

Third, the notch dimensions, shape and orientation. And last, the location of the notch.
These are detailed in the following sections.

4. Specifying EDM Notches

Let's delve into the information you would need to provide to the EDM manufacturer so that they can create a custom EDM notch.

Part supplied or manufactured

First decide whether you will be supplying the part to be notched or whether you want the manufacturer to machine it for you. If it's the latter, you probably need to make its design relatively simple in order to keep costs low. Machining an aircraft engine component is a very expensive undertaking.
Parts made from flat or round metal stock can be machined cost-effectively into standards.

Metal alloy designation or composition

Provide information regarding the metal alloy of the part. This allows the EDM Team to design the electrode to compensate for wear during the burn process. It also allows the Team to estimate the time required and quote appropriate pricing.

Define the shape of the EDM notch

The two most common shapes are shown in figures 4-1 and 4-2. Flat-bottom notches, also called "rectangular", have a flat bottom. Thumbnail-shaped notches, also called "radiused", "half-circle" or "half-penny", have a radiused bottom.
The most common ratio of Length-to-Depth is 2:1. If the specified Depth is larger than the Length a thumb-nail shaped notch will be rectangular at the top, with a radiused bottom.

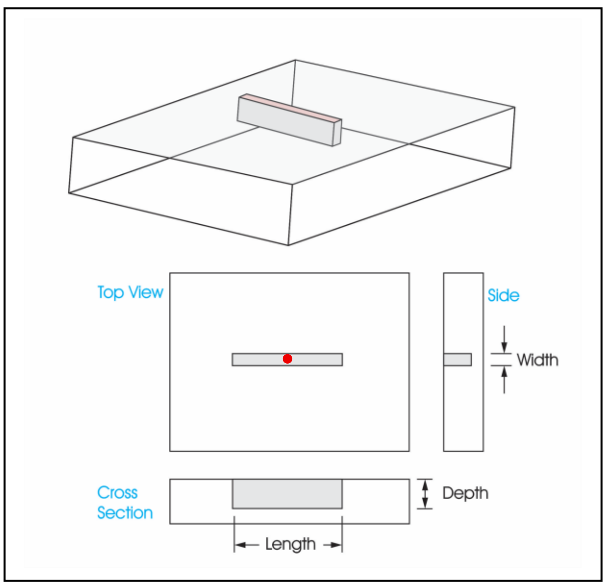

Fig. 4-1 Flat-bottom notch

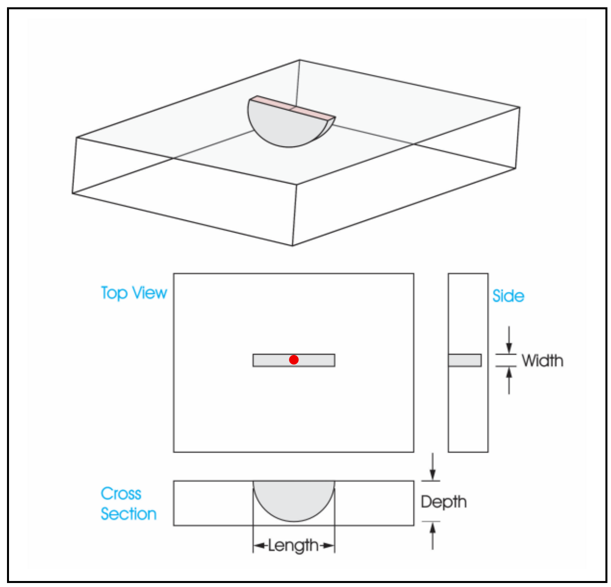

Fig. 4-2 Thumbnail notch

Do the EDM notches really look like the shapes shown in figures 4-1 and 4-2 when done? Close, but not quite exactly as shown. Very small amounts of the electrode get burned away during the process and the notch ends up slightly narrower at the bottom with the sides a bit more slanted. This is more pronounced for deeper notches. The amount is very, very small, less than 0.0002 inches (0.005 mm) for common notch dimensions, and often negligible.
Figure 4-3 shows a magnified picture of a 0.030 inch long x 0.015 inch deep x 0.003 inch wide notch in titanium. Figure 4-4 shows a 0.040x0.020x0.003 inch notch in aluminum. Note the slightly rounded ends. Also note the slightly fuzzy edges caused by slightly softer grains being easier to burn away.

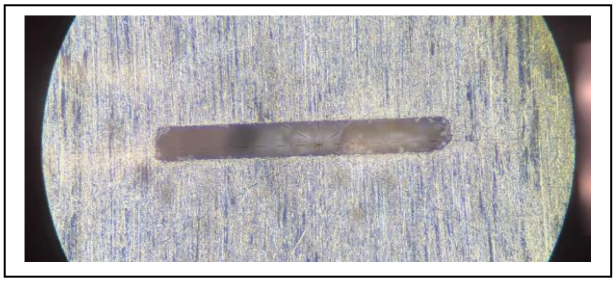

Fig. 4-3 Notch in Ti 6-4

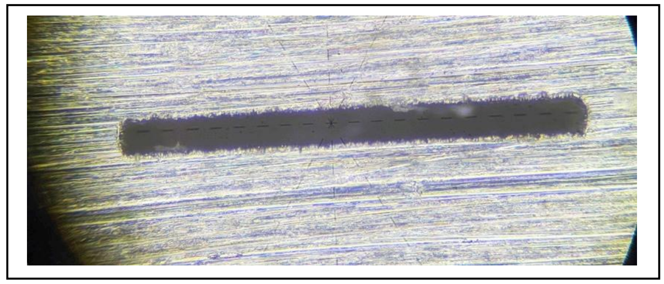

Fig. 4-4 Notch in Al 7075

Define the dimensions of the EDM notch

Common notations are Length x Depth x Width or Depth x Length x Width, with the larger number being the Length. This can sometimes lead to confusion if the depth is to be larger than the length.
It's best to add a letter, e.g. 0.030Lx0.015Dx0.004W would be a good way to specify a notch that is 0.030 inches (0.76mm) long, 0.015 inches (0.38mm) deep and 0.004 inches (0.10mm) wide.
Note that "Length" refers to the length of the electrode (not its height or width); the surface-length of the notch on a curved surface may end up being different depending on the depth of the notch.

I personally prefer Length x Depth x Width since the Length is the largest dimension that is visible when one looks at a notch. It is also the dimension that affects the electrode the most when it is made to the job.
Default units in the USA are inches. If you want dimensions in mm, please add "mm".

Tolerances: Typically, lengths and depths of notches are within +/-0.002 inches (+/-0.05mm) when burned. Widths are typically between 0.003-0.005 inches in final width.
If you decide on smaller tolerances, please specify them, but consider the issues mentioned above.
Members of EDM Teams normally get in contact with you if you specify dimensions or tolerances that are difficult to manufacture.

Dimensions of corner notches

Corner notches deserve special consideration since their shape depends on the shape of the corner of an edge. Their dimensions will be described below in Section 6.

Notch Orientation

When specifying notches on cylindrical objects you will need to specify their orientation.

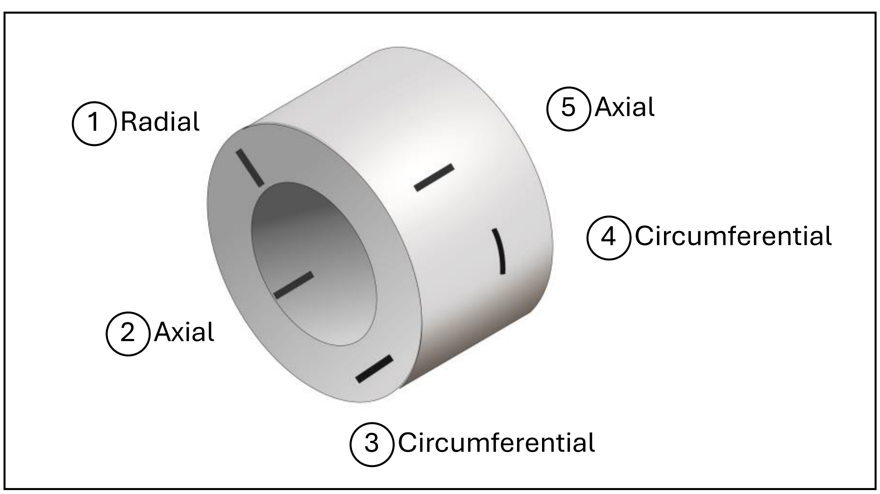

Fig. 4-5 Notch orientation on a cylindrical part

Figure 4-5 shows the common terminology for the orientation of a notch on a cylindrical part. For example, notch 1 is “radial” since its Length points radially outward from the center. Notches 3 and 4 are “circumferential” since their Length follows the circumference of the cylinder. This is the easiest way to denote orientation since it is based on a dimension of a notch that is visible.

Some engineers like to be a bit more detailed and add the Depth of the notch as an additional orientation. For example, notch 1 would be called “radial-axial”, i.e. the Length is “radial” and the Depth is “axial”. Notch 3 would be “circumferential-axial” and notch 4 would be “circumferential-radial”.
These descriptions will only work if the notch dimensions are “Length x Depth x Width”, otherwise things get confusing. I recommend staying with the simple terminology in figure 4-5 and provide a sketch or drawing.

Drawings

Besides specifying the characteristics of a notch as listed above, it is always helpful to provide a drawing to specify the location of a notch in order to avoid any confusion. This can be a formal drawing or a simple hand-drawn sketch. The examples in the next section show what dimensions are needed.

The location of a notch should refer to the center of the Length and Width of the notch (red dots in figures 4-1 and 4-2) relative to specific touch-off surfaces, edges or points.

5. EDM Notch Specification Examples

5.1 Flat-plate Reference Standard

Let's say that I would like a flat-plate standard with three EDM notches. Here is what I would need to specify:

1. Part: Not supplied, please manufacture.
2. Material: Titanium 6Al-4V; surface condition: 32Ra or better.
3. Dimensions: 4.00x2.00x0.50 as per drawing; all dimensions in inches; break all edges.
4. Notches:
   Three (3) EDM notches 0.040Lx0.020Dx0.002W, thumbnail (halfpenny)
   Tolerances: +/-0.002
   Locations and orientations as shown on the drawing
   Location-tolerance +/-0.010; angle tolerance: 2 degrees

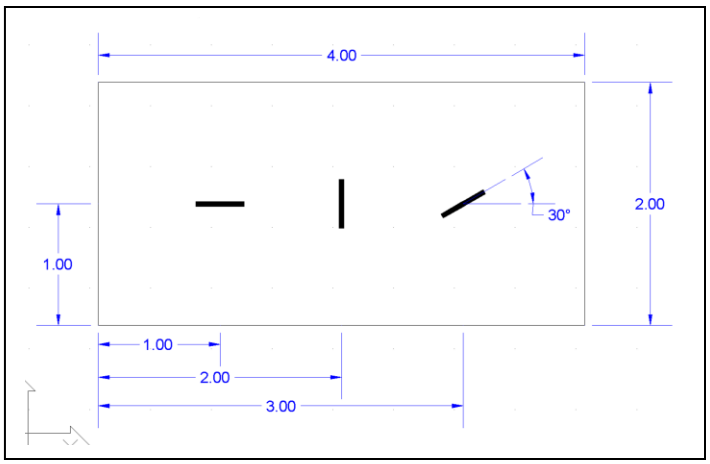

Fig. 5-1 Flat-plate reference standard drawing

The drawing shows the dimensions of the plate and the location and orientation of the three notches. The notches are not drawn to scale for visibility; specification 4 defines the actual dimensions and shape of the notches.

5.2 Cylindrical Standard

The standard is a cylinder/tube with two circumferential notches, one on the inner diameter (ID) and one on the outer diameter (OD). The cylinder will be supplied to the EDM Team. The specifications are:

1. Part: Supplied
2. Material: PH 17-4 steel; surface condition: 32Ra
3. Dimensions of part: 1.00 inch ID, 1.5 inch OD, 1.5 inch long
4. Notches:
   Two (2) EDM notches, dimensions in inches
   ID notch: 0.100Lx0.050Dx0.002W, thumbnail (halfpenny), circumferential, 0.20 inches from front edge at 0-degree mark
   OD notch: 0.160Lx0.080Dx0.002W, flat-bottom, circumferential 0.50 inches from front edge, 90-degree CCW (counterclockwise) from ID notch
   Notch tolerances: +/-0.003; location-tolerance: +/-0.010

These specifications are normally sufficient. If I want to make sure I get the correct notches I can add a 3D-sketch as shown in figure 5-1 or a drawing as shown in figure 5-3. I allowed a slightly larger tolerance because the notches are relatively deep.

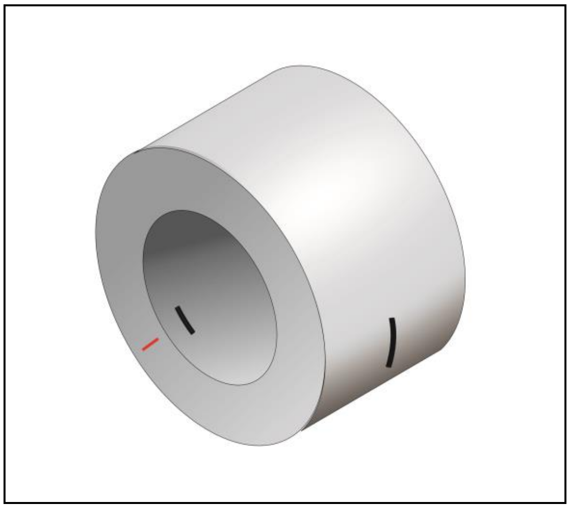

Fig. 5-2 3D-sketch of the cylinder

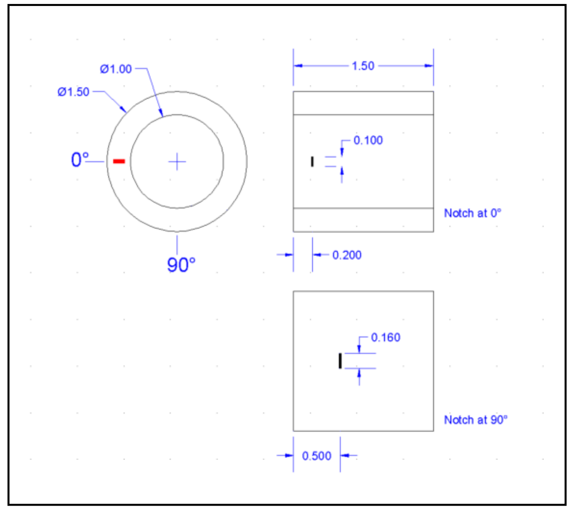

Fig. 5-3 Detailed drawing of the cylinder

When one defines notches on radiused surfaces one has to be aware of the shape of the electrode and where it touches the surface (the touch-off point) and design the depth accordingly.

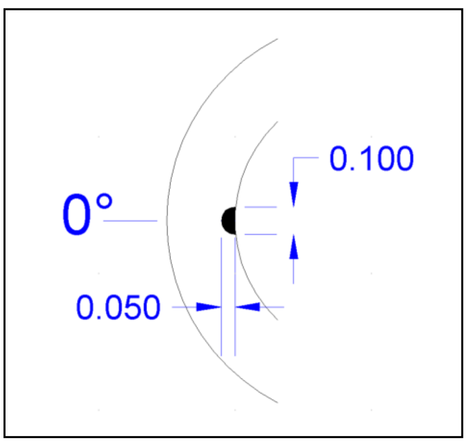

Fig. 5-4 ID notch, thumbnail

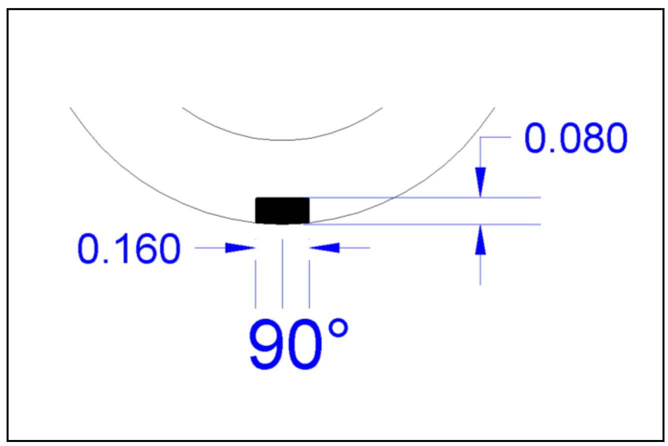

Fig. 5-5 OD notch, flat-bottom

Note the shape and depths of the ID and OD notches (figs. 5-4, 5-5): The cross-sections show that the final shapes are not quite “thumbnail” or “rectangular”. This is not critical for small notches on large curvatures but needs to be considered when placing long notches across small radii.

5.3 Turbine Blade Standard

Turbine blades used in aircraft engines or in power generators often require inspection at certain fracture-critical locations. One common area is the dovetail, the part of the blade that fits into the engine disk. Defining the notches is more complex and a drawing and model, if available, are essential.
An example dovetail of such a blade is shown in figure. 5-6. The blade itself has been removed from the image so that we can concentrate on the dovetail. The dovetail features two slot bottoms and one crest on each side.

Let me describe what my plan is for this dovetail and why I want certain notches.
I plan to inspect this dovetail with an eddy current array probe consisting of 64 individual sensor coils on a flexible substrate. I have tested this array using a long notch on a flat-plate standard and determined that the signal amplitudes from the individual coils are the same, with an amplitude drop of less than 3dB in the space between coils. I.e. the array should be well suited for this inspection.
I could calibrate the array on a flat plate by scanning a small notch and adjusting the gain of all coils based on the signal amplitude of the one coil that "catches" the notch.
What I now plan to do is to determine how this array behaves on an actual dovetail. To that purpose I want five notches as shown in figure 5-6.

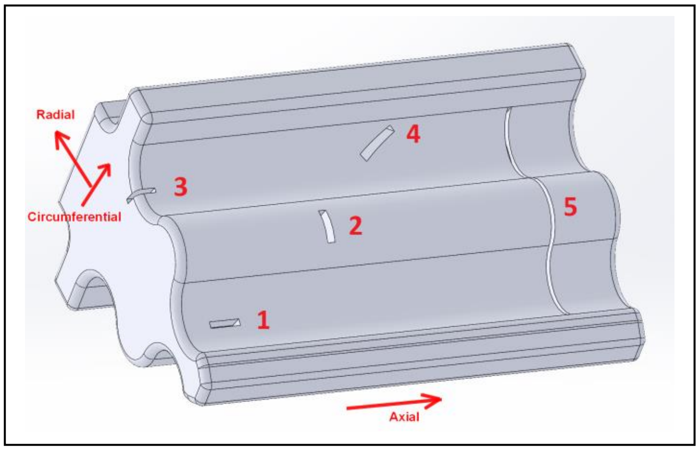

Fig. 5-6 Turbine blade dovetail with notches

Notch 5 is a long notch, similar to what I used on the flat-plate standard. Normally I would like to have a "infinite" notch which is a cut through the whole dovetail, because the coils in the array would respond to a well-defined notch-edge, independent of depth. Now, however, I want to try a notch with a depth of 0.020 inches that follows the contour. I am aware that it will be difficult to make such a notch with a consistent depth tolerance of +/-0.002 inches.
Notch 1 is a standard notch in a fracture-critical area, the slot-bottom. The other three notches are there to determine detectability. Let me specify all notches:

1. Part: Supplied
2. Material: Inconel 718
3. Dimensions of part: see drawings.
4. Notches (dimensions in inches):
   #1 - 0.030Lx0.015Dx0.002W, in slot-bottom, axial, thumbnail shape
   #2 - 0.040Lx0.020Dx0.002W, on slot crest, radial, flat-bottom shape
   #3 - 0.200Dx0.002W corner notch at 45 degrees in slot-bottom
   #4 - 0.040Lx0.020Dx0.002W, at up-slope, 45-degrees to axial direction, thumbnail shape
   #5 - 3.139Lx0.020Dx0.002W, contour-following
   Tolerances: +/-0.002

I would provide the sketch in figure 5-7, providing some dimensions of the dovetail and notch locations.

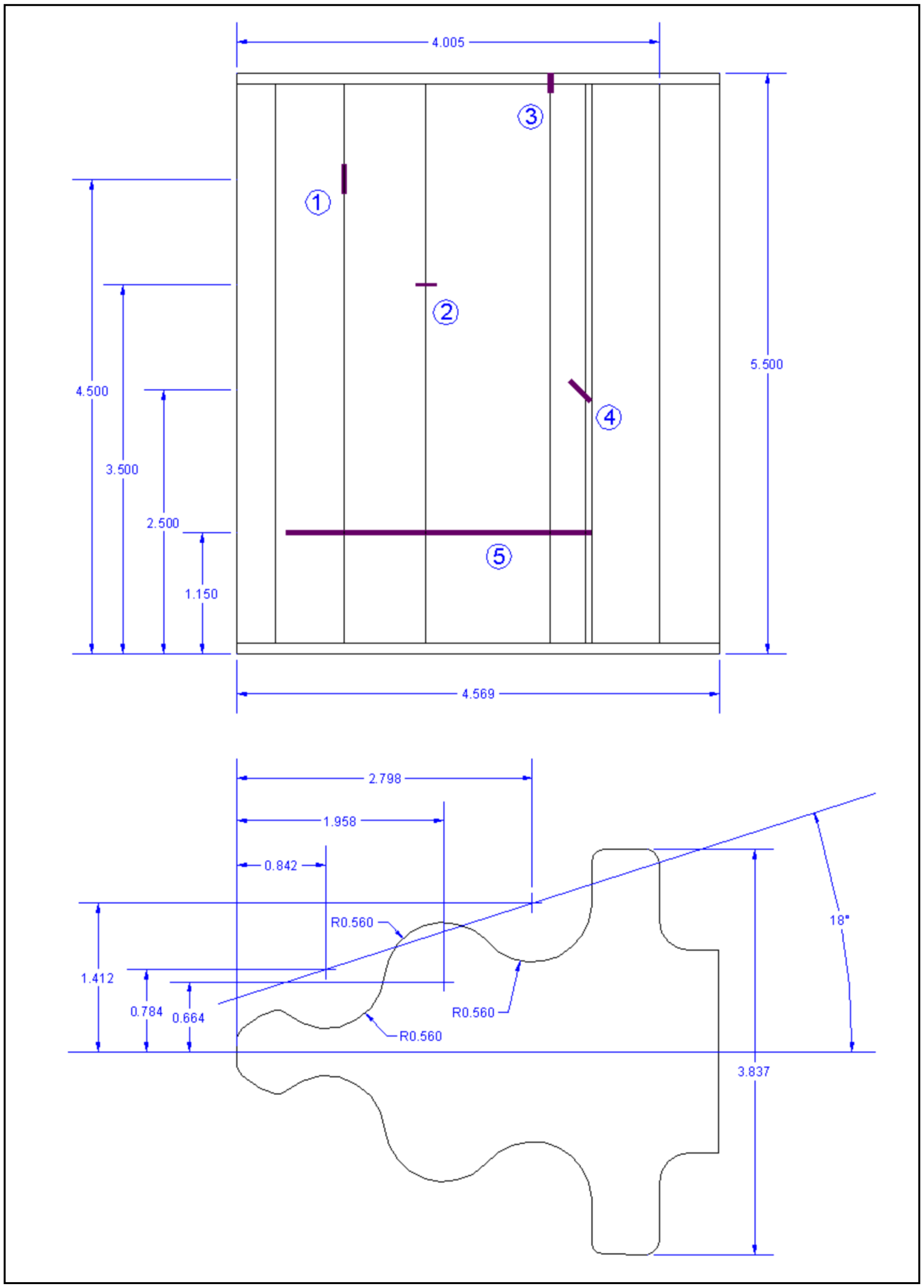

Fig. 5-7 Dovetail dimensions and notch locations

Notches 1, 2 and 3 are relatively easy to place with the EDM machine if the machine can locate minima and maxima. For completeness, however, I would provide drawings for each notch, with dimensions measured from a point or edges that the EDM Team can use as “touch-off” features.

There are two ways I can draw this. Method 1 uses the profile of the dovetail as shown in figure 5-7 with the front edge used as reference for the dimensions and as a touch-off point for the radial locations; the second touch-off point would be the tip of the first crest.
Method 2 consists of tilting the dovetail by 18 degrees, which puts the slot-bottoms horizontal, avoiding the need for providing notch-angles for notches 1,2 and 3. Notch 4 however requires a steeper angle.

In the following drawings Method 1 is on the left, Method 2 is on the right.

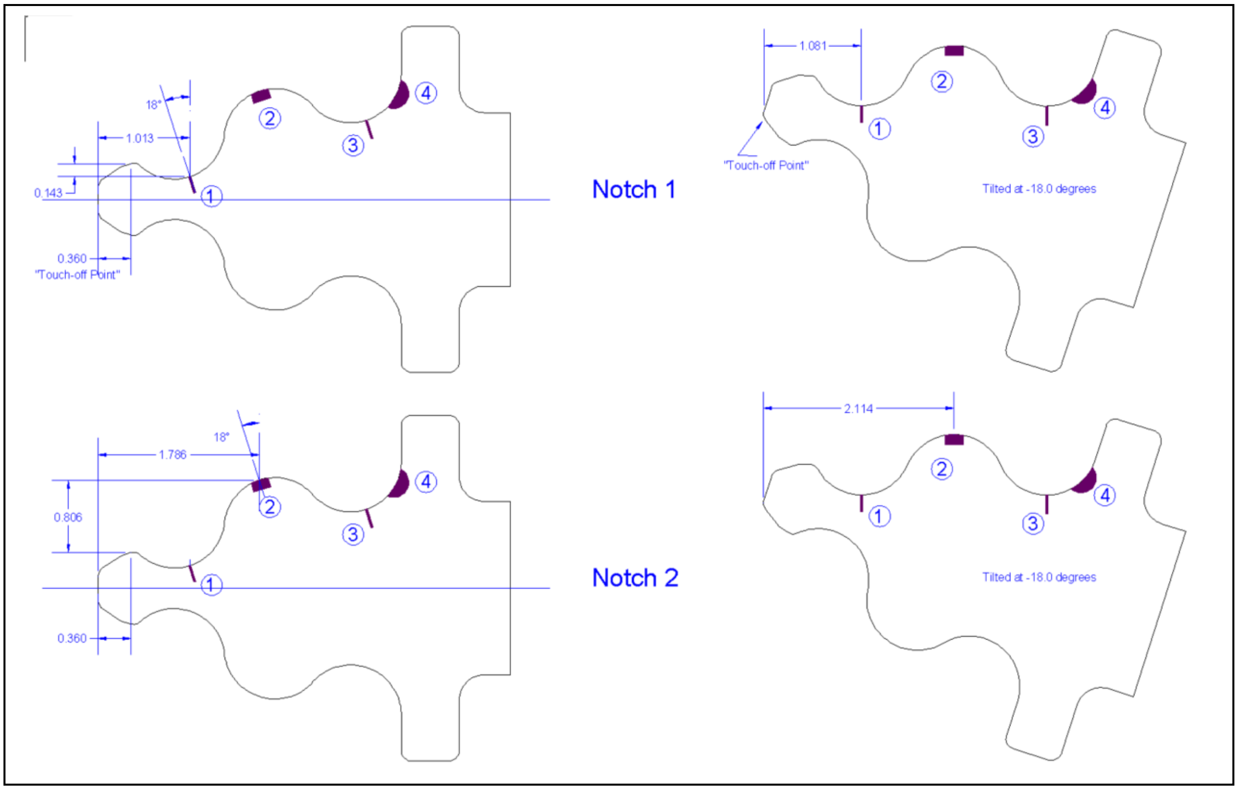

Fig. 5-8 Method 1 and Method 2 drawings for notches 1 and 2

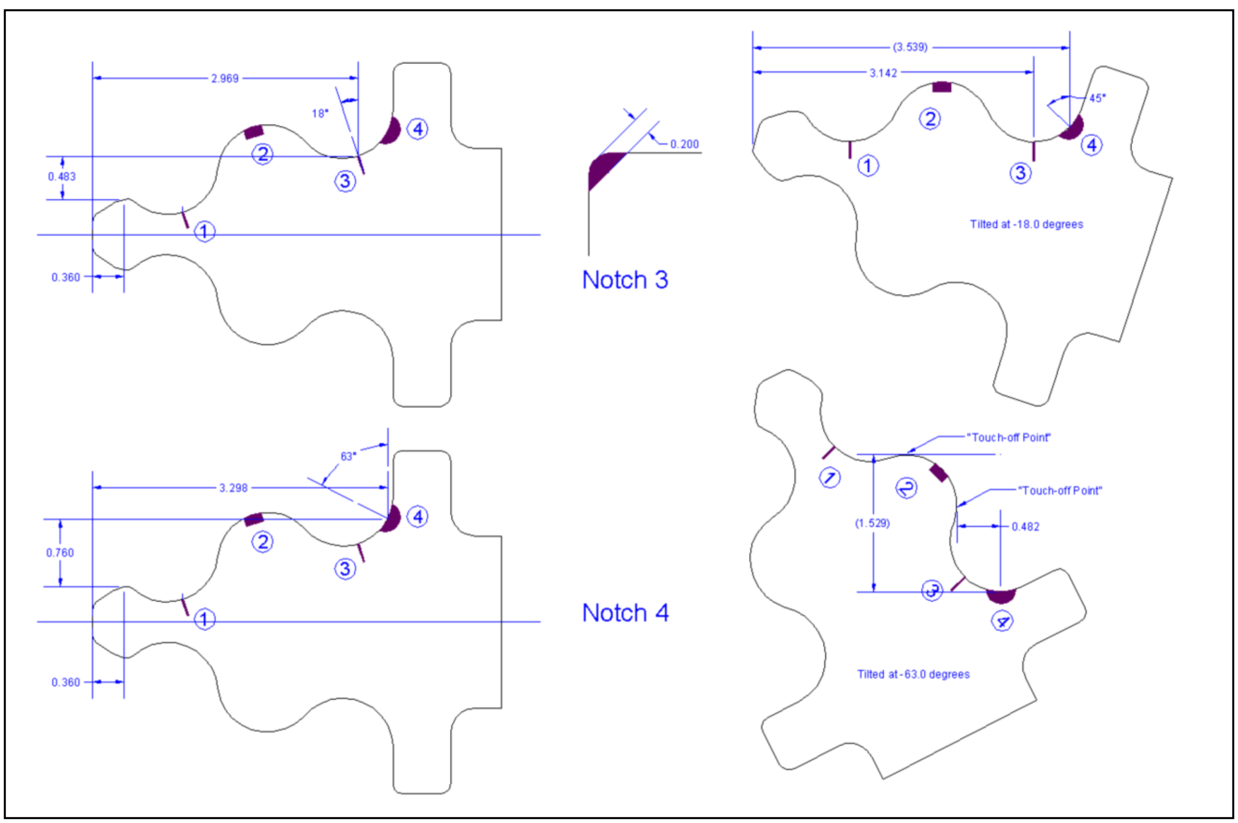

Fig. 5-9 Method 1 and Method 2 drawings for notches 3 and 4

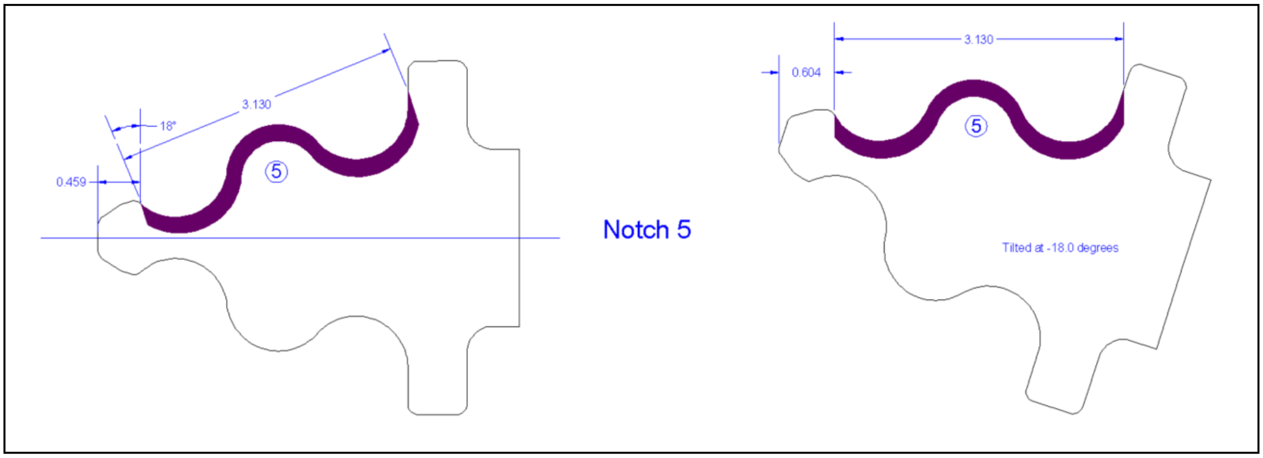

Fig. 5-10 Method 1 and Method 2 drawings for notch 5

My preference is Method 2. Dimensions in parentheses are provided for additional assistance.

5.4 Broach Standard

Now that I defined the notches for the dovetail of the turbine blade, how about the broach slot of the engine disk that holds the blades?
Let's define the notches for an appropriate reference standard.

1. Part: Supplied
2. Material: Inconel 718
3. Dimensions of part: see drawings
4. Notches (dimensions in inches):
   #1 - 0.030Lx0.015Dx0.002W, on inner pressure face, axial, thumbnail shape
   #2 - 0.030Lx0.015Dx0.002W, on outer pressure face, axial, thumbnail shape
   Tolerances: +/-0.002

I will definitively need to supply sketches or drawings. If exact drawings with slot dimensions and tolerances are not available, the first sketch I provide is similar to the sketch of the profile in figure 5-7. This gives the EDM Team an idea of size and allows the manufacturers drafters to create a drawing if needed.
The second drawing is shown in figure 5-11. It contains dimensions that assist the EDM team with touch-off points. One touch-off point is the broach bottom surface. Additional touch-off points could be the locations of the first, "inner", crests. What is really helpful is an inner circle in the bottom slot. The latter allows the EDM Team to build tooling that can be used as touch-point references.

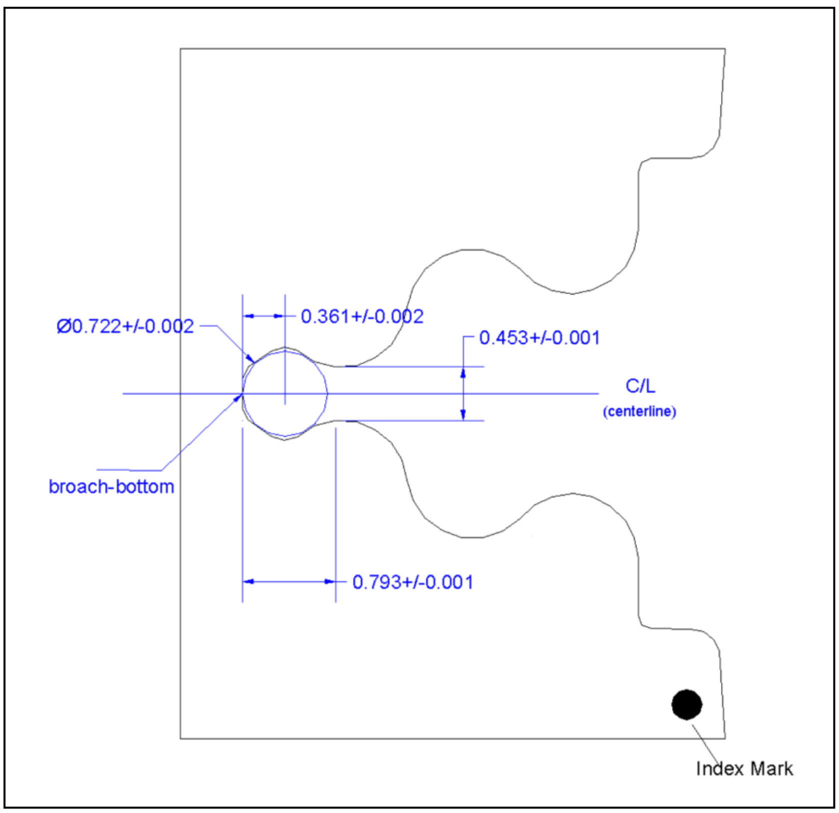

Fig. 5-11 Dimensions that assist the EDM Team in locating EDM notches

The third drawing to provide contains the locations of the EDM notches. Figure 5-12 shows their placement relative to the broach bottom, their angles, and their axial placement relative to the edge of the broach surface.

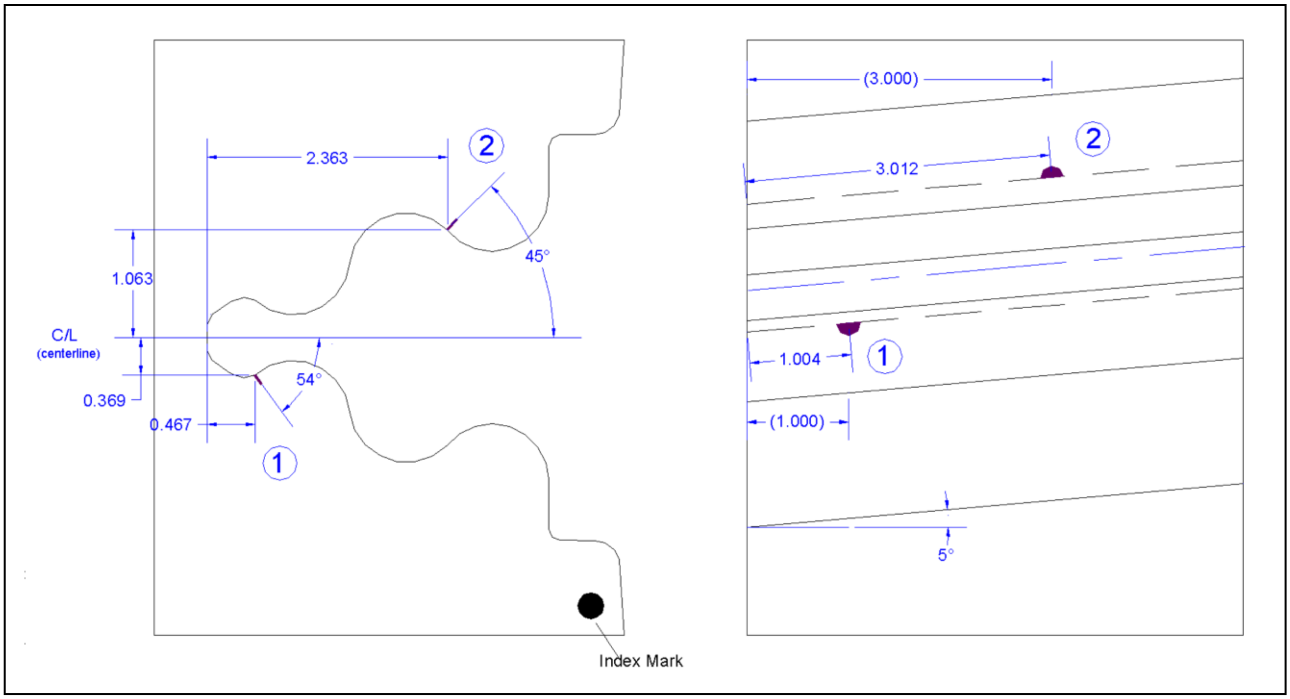

Fig. 5-12 Locations of the EDM notches

I gave two dimensions for their axial placement, one from the edge based on the 5-degree tilt of the slot and one based on drawing-alignment in parentheses. The latter is not really necessary since the EDM Team can do calculations. However, stating the 5-degree angle of the broach slot is critical since it defines the axial angle of the notches.

Note: In order to make a probe for the dovetail or the broach slot, the engineering group of the probe manufacturer will definitively need a formal drawing with precise dimensions and tolerances. This allows them to design a probe that actually has a chance of fitting.
Stating the critical inspections zones helps with positioning the sensor coils and providing several actual parts allows them to fit it all together. Please do allow for 2-3 iterations of probes due to physical variations of the parts.

5.5 Engine Disk Standard

Now that I have the notches laid out in the more difficult parts, like the broach-slots, I'm considering placing EDM notches into an engine disk, i.e. a rotationally symmetric part with multiple contours. The disk is shown in figure 5-13 and the layout of the notches in figure 5-14 (the notches on the bore surface are not visible).

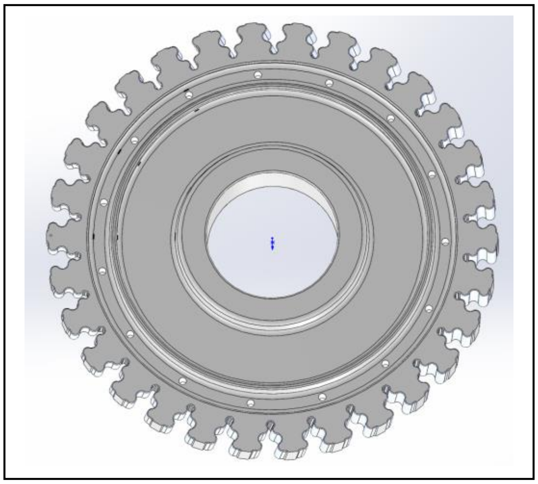

Fig. 5-13 Engine disk example

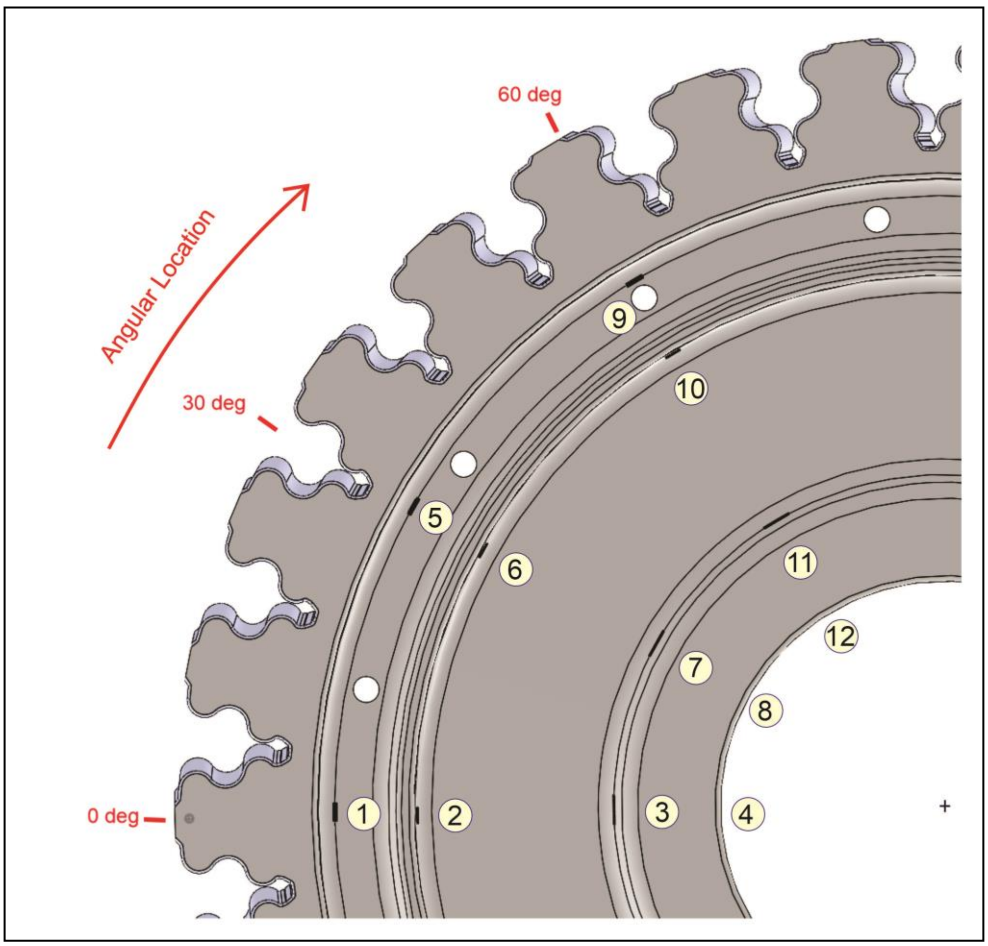

Fig. 5-14 Engine disk notch layout

The specifications are:

1. Part: Supplied
2. Material: Inconel 718
3. Dimensions of part: see drawings.
4. Notches (dimensions in inches): 12 EDM notches per table below

Notch Number	Length x Depth x Width	Notch Orientation	Shape	Angular Location	Location
1	0.020x0.010x0.003	Circumferential	Thumbnail	0	See drawing
2	0.020x0.010x0.003	Circumferential	Thumbnail	0	See drawing
3	0.020x0.010x0.003	Circumferential	Thumbnail	0	See drawing
4	0.020x0.010x0.003	Axial	Thumbnail	0	See drawing
5	0.030x0.015x0.003	Circumferential	Thumbnail	30	See drawing
6	0.030x0.015x0.003	Circumferential	Thumbnail	30	See drawing
7	0.030x0.015x0.003	Circumferential	Thumbnail	30	See drawing
8	0.030x0.015x0.003	Axial	Thumbnail	30	See drawing
9	0.040x0.020x0.003	Circumferential	Thumbnail	60	See drawing
10	0.040x0.020x0.003	Circumferential	Thumbnail	60	See drawing
11	0.040x0.020x0.003	Circumferential	Thumbnail	60	See drawing
12	0.040x0.020x0.003	Axial	Thumbnail	60	See drawing

Notch dimension tolerances: +/- 0.002 inches
Angular location tolerance: +/- 5 degrees

There are twelve EDM notches of different dimensions spaced at different angular locations around the disk. These allow me to determine what the limits of detectability are for a particular probe or inspection system. Of particular interest is notch 9 since it is next to a hole and the signal response due to the edges of the hole may be larger than the signal responses from notches 1, 5 and 9. If the response from the hole is larger, then the inspection of this zone may require a special probe.

I need to provide several sketches or drawings besides figure 5-14. Figure 5-15 shows the major dimensions of the disk. This helps the EDM Team to set up the disk in the EDM machine. The Team can use the surfaces of the bore and bore-face for "touch-off". The 0-degree angular location is generally marked by an index line or the "S" of the serial-number etched on the outside rim of the disk.

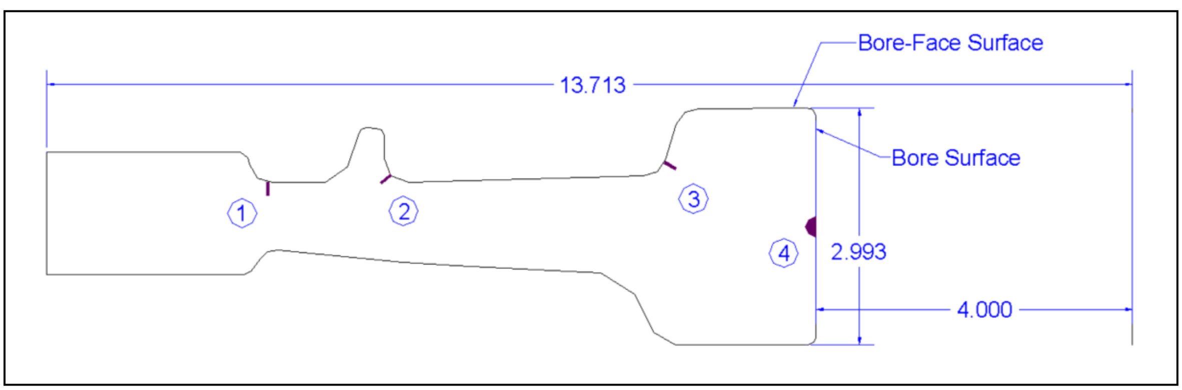

Fig. 5-15 Cross-section of the disk at 0-degrees with major dimensions and orientations of the first 4 four notches

Next, I provide drawings of the notches (figures 5-16, 5-17, 5-18 and 5-19).

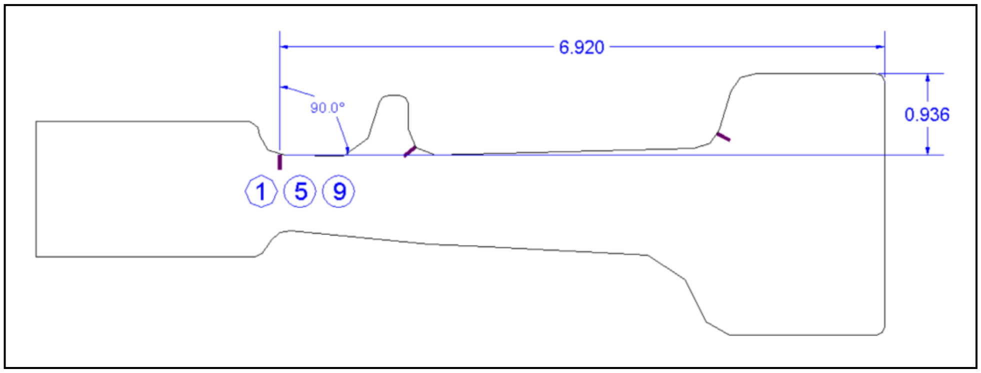

Fig. 5-16 Location drawing for notches 1, 5 and 9

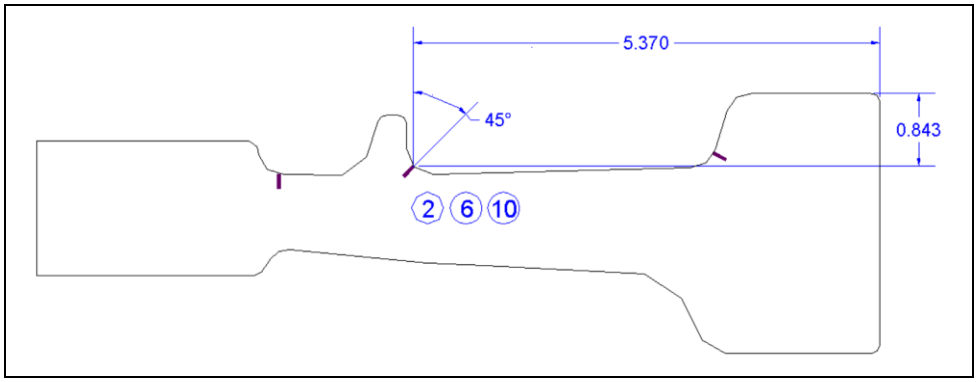

Fig. 5-17 Location drawing for notches 2, 6 and 10

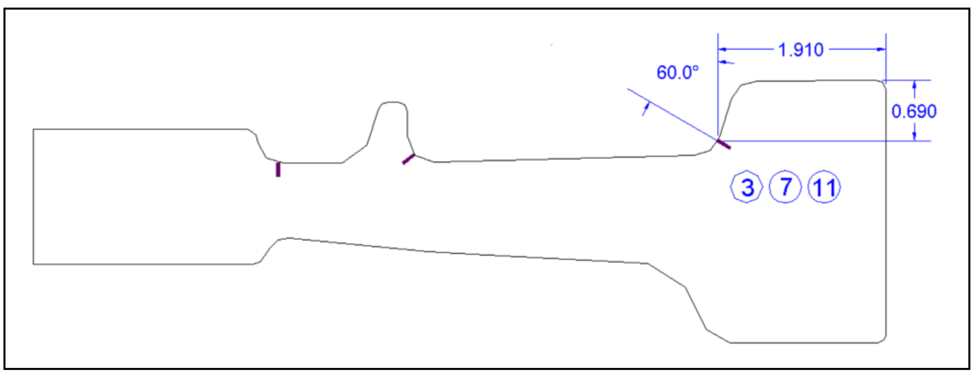

Fig. 5-18 Location drawing for notches 3, 7 and 11

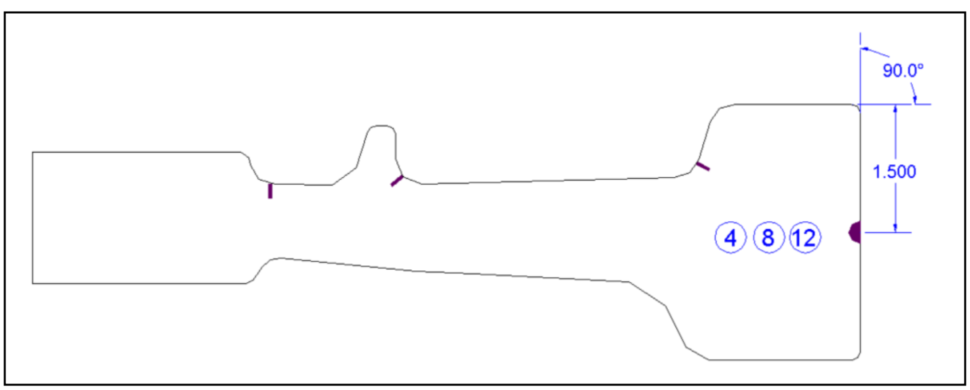

Fig. 5-19 Location drawing for notches 4, 8 and 12

This information should be sufficient to create the disk reference standard. Note that the dimensions for the notch locations have three significant figures after the decimal. On mechanical drawings this generally implies a tolerance of +/-0.005 inches. Since the disk supplied to the EDM Team has its own dimensional tolerances, the EDM notch positions may vary slightly in the final standard.

Please do not ask the EDM Team to provide the actual final locations. This requires very expensive optical instrumentation that is not generally available.

5.6 Threads

Now to something that appears simple but can lead to confusion: Specifying EDM notches in threads.

There are external threads (OD thread), such as on bolts or threaded shafts. And internal threads (ID thread) in parts that get bolted together.
Based on my experience, both of these can form cracks if under sufficient stress. Most of the cracks I have seen start in the root of the third or fourth thread from the shank of a bolt or from the face of an ID thread, migrate along the root for a bit and then shift into an axial direction. The reason is that this location is under the highest load when threads engage. Often bolts also seem to crack in the contact areas between the shank and the head when they are mounted flush to an ID thread.
Of course, there could be hidden material flaws that start opening up when a bolt and its mating part are put together and put under stress. A classic flaw is an internal seam in the rod from which a bolt is made. Seams of that type are incredibly difficult to detect. But that's a different topic.

OD-Thread - Bolt

Let's specify EDM notches for a custom-made bolt that I plan to give to an EDM Team for notching. Figure 5-20 shows the custom bolt with four EDM notches and figure 5-21 the drawing I plan to supply.

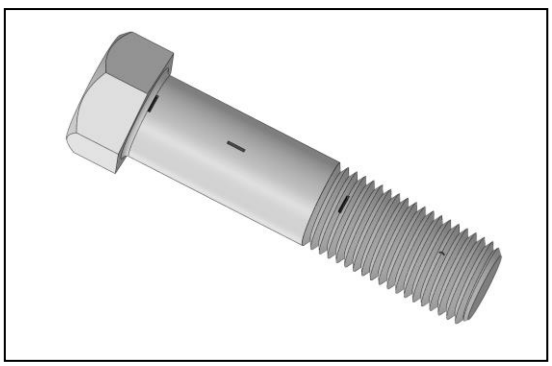

Fig. 5-20 Example bolt with four notches

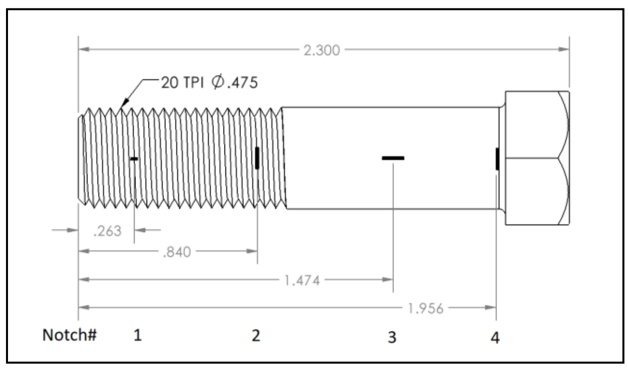

Fig. 5-21 Drawing of the bolt

I also plan to supply the following specifications:

1. Part: Supplied
2. Material: 304 Stainless Steel, custom-made
3. Dimensions of part: see drawing.
4. Notches (dimensions in inches):
   #1 - 0.040Dx.003W, flat-bottom, on thread crown
   #2 - 0.040Lx0.020Dx0.003W, flat-bottom, in root, following root angle
   #3 - 0.040x0.010Dx0.003W, flat bottom, axial, on shank
   #4 - 0.040x0.020Dx0.003W, flat bottom, circumferential, at shank radius to head
   Tolerances: +/-0.002

This may look sufficient but it is going to be difficult. The dimensioning of the location on the thread makes it awkward. If notch#2, in the root, needs to be at exactly 0.840 inches from the end of the bolt, the EDM technician will have to rotate the bolt many times, with touch-off at the end of the bold, until he finds a thread root at that exact distance. This requires lots of time and becomes costly.

A better way would be to have a note on the drawing that states "approximate locations only". And then specify the notches as follows:

#1 - 0.040Dx.003W, flat-bottom, on thread crown, fifth full-thread up from the end of the bolt
#2 - 0.040Lx0.020Dx0.003W, flat-bottom, in root, following root angle, third of fourth thread from shank, in-line with #1
#3 - 0.040x0.010Dx0.003W, flat bottom, axial, mid-shank, in-line with #1
#4 - 0.040x0.020Dx0.003W, flat bottom, circumferential, at start of radius on shank, in-line with #1
Tolerances: +/-0.002

This allows the EDM technician to find the fifth full crown from the end of the bolt, mark the location of notch#1, mark the location of the other 3 notches and then place the bolt in the EDM machine for notching. This is easier and faster.

ID-Thread

Let's specify EDM notches for the part that will mate to the bolt above.

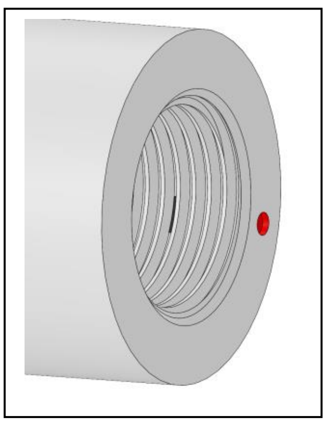

Fig. 5-22 Notch in thread root

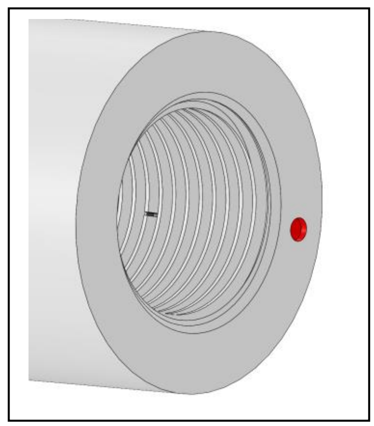

Fig. 5-23 Notch in thread crown

I need to supply the following specifications:

1. Part: Supplied
2. Material: 304 Stainless Steel, custom-made
3. Dimensions of part: 20 TPI x 0.475 inch
4. Notches (dimensions in inches):
   #1 - 0.040Lx0.020Dx0.003W, flat-bottom, in root, following root angle, third of fourth thread from face,
   #2 - 0.040Dx.003W, flat-bottom, on thread crown, 8^{th} or 9^{th} thread up from the face, inline with #1.
5. Mark axial location of notches with an index mark on the face of the part, 0.15 inch from thread.

I am not providing a drawing. I do need to specify the thread-size to make it easier for the EDM Team to estimate notch location. I also ask for machining or engraving an index-mark to make it easier for me to locate the notches later.

6. Special Considerations – Corner Notches

Notches placed into the corners of edges require a bit more discussion. An example of a corner notch is Notch 3 in figure 5-6 at the bottom-edge of the slot of the dovetail. The word "corner notch" is a bit of a misnomer since one does not put notches into 3D-corners but only into corners at edges.
There are three types of common corner notches. These are shown in figure 6-1.

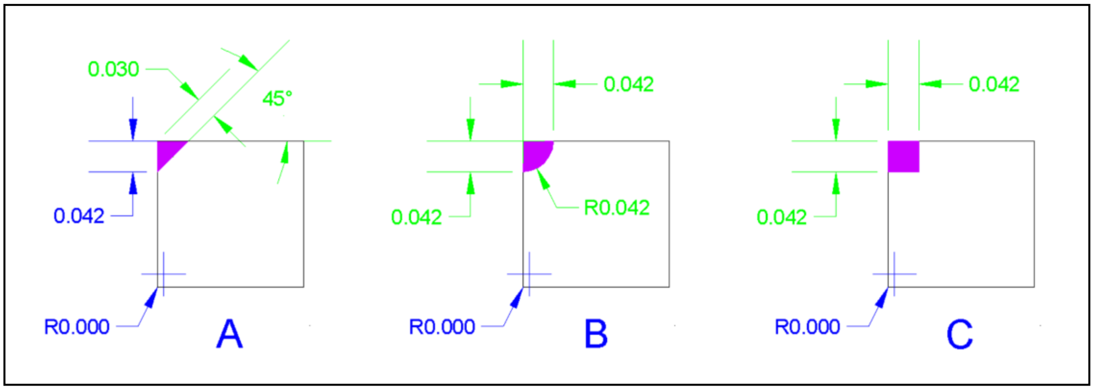

Fig. 6-1 Typical corner notches

In this and the following figures, the dimensions in green color are part of the notch specification. Dimensions in blue or magenta are the dimensions one ends up with.

Figure 6-1A shows a flat-bottom notch created by using a flat-bottom electrode and plunging it into the edge at 45 degrees to a depth of 0.030 inches. The resultant *surface-length* of the notch is 0.042 inches, which is what the eddy current probe ends up "seeing", i.e. it is the major contributor to the eddy current signal response. This specification is very common. One can also specify notches at different angles if desired.
The next common notch shape (thumbnail or half-penny) is shown in figure 6-1B. It is defined by specifying the radius of the electrode to be used and the depth of the notch from the left and top surfaces that make up the edge.
The last type (rectangular) is shown in figure 6-1C. This shape is not very common but does exist.

All three notch shapes are easy to specify and relatively easy to machine.

As an engineer specifying notches, I need to be aware of two things:

- Is the edge that I plan to EDM sharp, radiused (i.e. a fillet) or slanted (i.e. a chamfer)? and
- Can I scan that edge with a probe?

Edges are notoriously difficult to inspect mainly because often they are not straight lines but follow contours. The radiused edges of the dovetail in figure 5-6 are an example. It is nearly impossible to design an eddy current probe that can follow such a contour, especially if the radii are small and if there are multiple compound radii present. Often one inspects such an edge by scanning across it from a "benign" surface, e.g. from the slot bottom outwards. For this to be successful, the corner notch needs to extend a bit into the surface. And this is where the specification of the EDM notch needs to consider the shape of the edge.
Let's look at the effect of the radius of the edge on the final shape of a corner notch.

Figure 6-2 shows what the cross-section of a notch would look like when burning it with a flat electrode at 45 degrees, to a specified depth of 0.030 inches into corners with different radii. In this case, even though the surface-length of the notch decreases, the cross-sectional area of the notch increases. and the signal response may not vary too much.

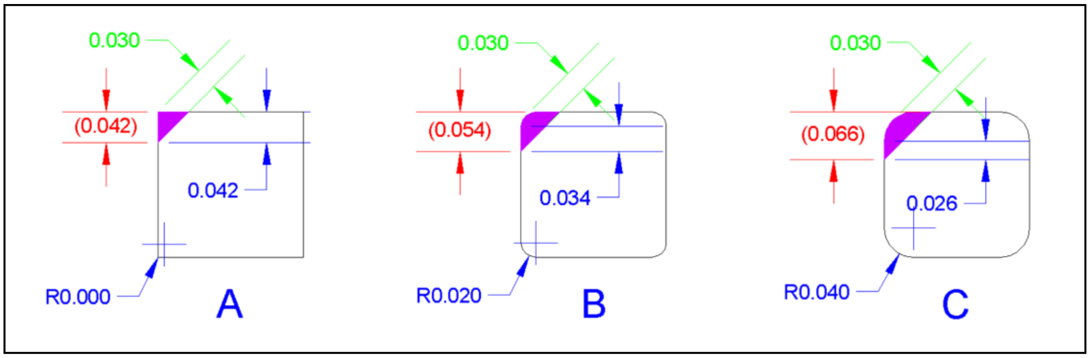

Fig. 6-2 Corner notch cut at 45 degrees to a depth of 0.030 inches into different edge radii

However, when we specify the surface length rather than depth, e.g. 0.042 inches in figure 6-3, not only will the surface-length of the notch decrease with increasing edge radii, but also its cross-sectional area. The signal response from the notch will decrease drastically with increasing edge radius.

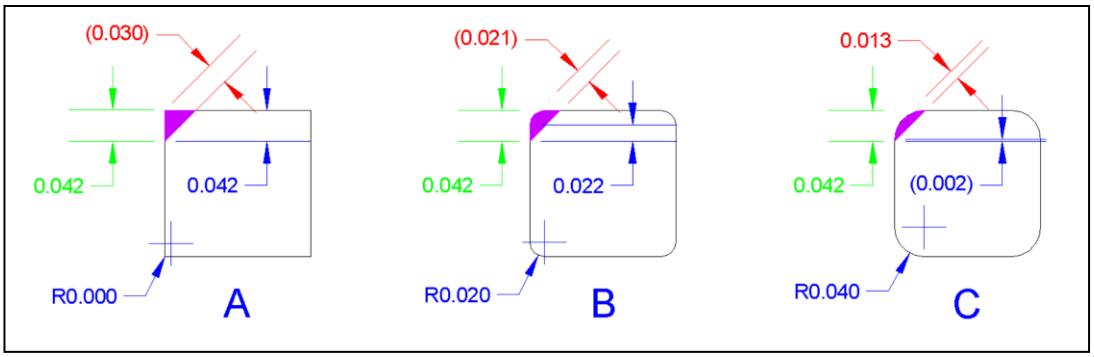

Fig. 6-3 Corner notch with edge distance of 0.042 inches into different edge radii

Figure 6-4 shows the effect of using a radiused electrode to cut the EDM notch. The effect is not as dramatic as in figure 6-3, but still present.

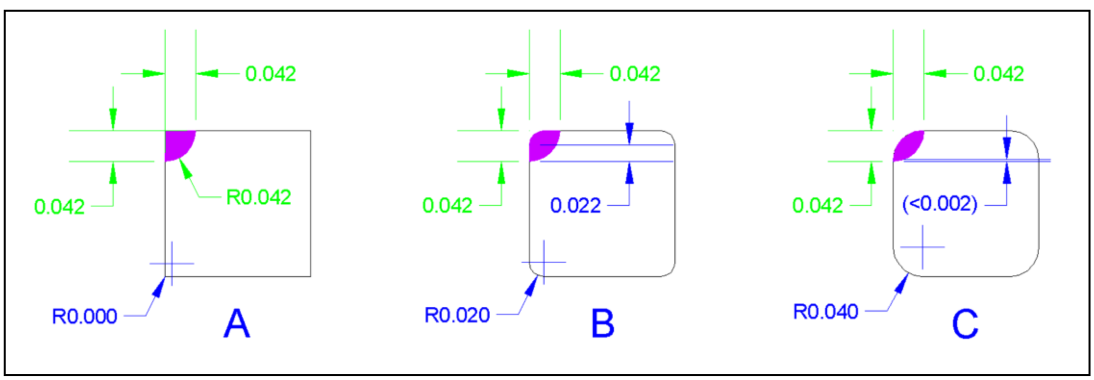

Fig. 6-4 Radiused corner notch cut to distances of 0.042 inches into different edge radii

Corner notch detectability is generally difficult and needs to be considered carefully, especially when edge-radii can vary, which is common when blended manually.

The examples above use a 0.042 inch surface length based on a 0.030 inch depth in order to demonstrate the effects of edge radii. More common specifications are

- 0.030x0.030 length measured from the edges (independent of radius).
- 0.030x0.030 surface length measured from the transition of the edge radius to the flats.
- 0.015x0.015 surface length measured from the transition of the edge radius to the flats.

As mentioned above, edges are difficult to inspect. The major problem is that eddy current responses to edges are generally larger than the responses to flaws on the edges. This provides a significant challenge to probe-designers and the developers of inspection procedures.

7. Marking

A reference standard needs some means to be identified. This identifier will be used on certificates provided by the EDM Team.

Aircraft engine disks commonly have a part-number and serial number engraved or etched at a specific location that can be used to identify the part. The first letter of the serial number is often used as the "reference point" for circumferential locations of EDM notches.

For standards made from plates, blocks, blades, or segments cut from parts, you should provide locations where you would like the EDM Team to place identifiers, such as a part-number and a serial number.
If you do not provide numbers, EDM Teams will assign their own number (e.g. the purchase order number) and a serial number.

Naturally, any engraving of the identifier needs to be on a surface or at a location that is not being scanned during the eddy current calibration or inspection process.
This will be difficult to do on bolts. If the head of the bolt is relatively large and the top is flat, engraving it may be possible.

Always store reference standards in a safe place that prevents them from being damaged.

Color-Marking
I often color-mark my standards by spraying a non-relevant surface with spray-paint to identify that the part is a Reference Standard, to be treated with care and respect. Figures 7-1 and 7-2 show two examples.

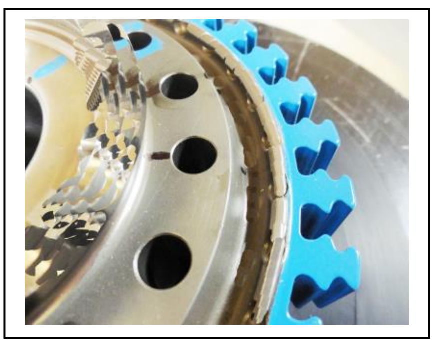

Fig. 7-1 Color-marked disk

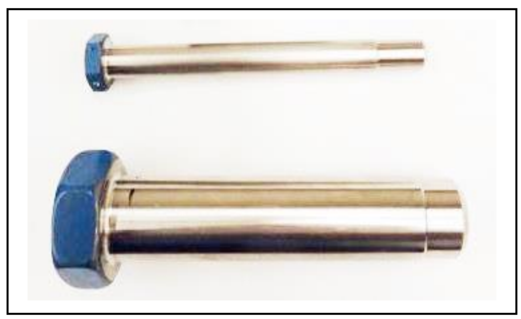

Fig. 7-2 Color-marked bolts

But be careful: Blue is a good color because few people know what it means and will ask before disposing the part. Red is a bad color: Many years ago, a friend of mine lost 5 aircraft engine standards worth over $250k because he marked them with red paint. Red was considered "Reject -Scrap" and the night-shift in his company disposed of them.

8. Documentation

The final step in the production of a reference standard consists of certifying the sizes of the notches. In addition to the depth-value provided by the EDM machine, the notch depth, length and width are optically measured and recorded on a certificate.

An optional service called "replication" is often available. This process consists of filling the notch with a silicon compound. Once hardened the replication is removed, photographed and measured. The replication shows the exact shape of the final notch.

9. Questions and Answers

In the following section, I will try to answer some of the questions I have received over the years.

Q1. *What metal alloy should I specify when I want a standard made, such as the flat plate in Example 1?*

A1. For eddy current testing you want an alloy with an electrical conductivity value as close as possible to the part that you will be inspecting. Ideally you want exactly the same alloy.
Some aircraft engine components are manufactured from custom alloys. In this case it would be best to provide a piece of the same alloy or a section of the part to the manufacturer of the standard. Or make a standard out of a complete part such as an engine disk or turbine blade.

Q2. *I will be supplying the part for EDM notching. Can I send a part that has been in-service?*

A2. This depends on the condition of the in-service part. If the part has seen extensive wear and is damaged, the eddy current signal responses from the damages may exceed the signal responses from EDM notches. I.e. it will not serve as a good reference standard.
Ideally you would make the standard from a new part. In the case of aircraft engine disks this would be expensive. In this case you could use a development part that was rejected but has the same features that you would like to inspect on the final parts.
In any case, make sure that the part is clean and free of debris.

Q3. *The EDM Team made a mistake and placed one of the notches in the wrong location in the part I supplied. What shall I do?*

A3. Normally the EDM Team will contact you if they make a mistake with the location or size of an EDM notch. They will ask if you would be ok if they place the correct notch at a slightly different location. Usually they will do this at no charge. The EDM Certificate will have a note regarding this change.

Q4. *How often shall I have my reference standard recertified?*

A4. This is up to you and your company's quality control requirements. Very few companies in the world have reference standards re-certified because realistically there is no need.
Eddy current probes are normally made from plastic materials to avoid damaging parts during inspections. Many times, the probes are covered with Teflon tape prior to inspections to reduce probe-wear. Therefore, reference standard experience little or no wear at all.
If they would experience wear, it would not be detrimental: The notch would become shallower and hence any inspections would effectively become more sensitive. i.e. you would be inspecting on the "safe side".

10. Final Remarks

I hope this document is useful to you.
The next page features an example request form that you can provide to the manufacturer of the EDM notches and standards to help with the quotation process.
More detailed information may be required once you have ordered the standard or notches.

EDM Request Submittal Form

Please provide the information below in order to assist the EDM Technicians in estimating cost and delivery times.

Contact Information

Company: ____

Address: ____

Contact Person Name: ___________________________________

Phone number: ___________________________________

Email address: ___________________________________

Part Information

1. Part: Supplied To be manufactured (please circle)
2. Material: ____
3. Dimensions of part: Drawing/Sketch/Photo supplied Not supplied (please circle)
4. Total number of notches: __________

Notch dimensions: (please provide a separate sheet or a drawing later if more than 4 total notches are required or if requested by the EDM Technicians)

Index	Length	Depth	Width	Shape
Example	0.040	0.020	0.003	Thumbnail
1				
2				
3				
4				

Tolerances: ______________________________

Units: inches mm (please circle)

Special Requests

Engraving Description: Description provided Description not provided (please circle)

Replication desired: yes no (please circle)

Other: