EDM Specialty Gears

From the Mars Lander to car doors, gears cut with EDM find their niche.

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Introduction

The capabilities and limitations of manufacturing gears by conventional means are well-known and thoroughly documented. In the search to enhance or otherwise improve the gear-making process, manufacturing methods have extended beyond chip-cutting—hobbing, broaching, shaping, shaving, grinding, etc.—and their inherent limitations based on cutter selection and speed, feed rates, chip thickness per tooth, cutting pressure, cutter deflection, chatter, surface finish, material hardness, machine rigidity, tooling, setup and other items.

In this expanded search for improvement, EDM (Electrical Discharge Machining) has been utilized in more and more cases. EDM involves very few of the above criteria, thereby eliminating many of the problems associated with traditional methods. Granted, EDM can create some of its own problems, but on the whole, it makes design and manufacture of certain applications much simpler than conventional means. This article will examine a few examples.

The Process

Very briefly, EDM is a machining process that removes material by spark erosion. Using special generators, pulsed DC or AC current is used to vaporize and melt conductive material away instead of mechanically shearing a chip, as in conventional machining. The current is delivered to the workpiece via an electrode. Depending upon the application and machine, the electrode can be a small diameter alloy wire, as in the case of wire EDM or a pre-shaped, solid electrode that is used in a vertical or "sinker" EDM.

The spark gap of each machine type must be flushed with a dielectric fluid which is integral to the EDM process. The wire EDM uses deionized water that is regulated within a self-contained, closed-loop filtration and deionization system. The vertical EDM typically uses a specially engineered dielectric oil similar to kerosene, but with a high flash point. Both machines can use either as a dielectric, but as a rule, wire machines use DI water, and vertical EDM machines use a light oil engineered specifically for EDM use.

The Project

The first application is a gear assembly that is part of the drive mechanism that will retract the protective airbags, enabling other actuators to reorient the Mars Pathfinder Vehicle after its projected landing on Mars in July of 1997 (see sidebar). Since the lander may come to rest in any position, (upside down, sideways, etc.), this mechanism's task is to right the vehicle into its "heads up" position so it can function properly. The development and design of this complex and challenging project is being done by the Jet Propulsion Laboratory (JPL) in Pasadena, CA.

Four gears were required within one component of the Pathfinder Lander deployment mechanism called the airbag retraction actuator or ARA. Two of the gears were produced using a wire-cut EDM. This is a machine tool that can cut almost any conductive material using an electrically charged wire as a cutting electrode. The wire passes through the workpiece as the machine acts like an electric band saw. The wire electrode is usually made of various brass alloys and ranges in sizes from .001–.012" in diameter. For these gears, a brass wire of .008" diameter was used.

Because the wire electrode must pass completely through the part or outside of it along its periphery, spur gears are an ideal application for wire EDM, but gears located against larger shoulders or another larger diameter gear on the same shaft cannot be wire-cut. For them a vertical EDM or "sinker" must be used.

Instead of using a wire electrode, a vertical EDM uses solid, pre-shaped electrodes typically made of copper or a special graphite refined specifically for EDM use. These electrodes are made with the obverse shape of the desired details. For example, a free-standing male pinion gear located against a shoulder would be machined with a female electrode. The electrodes used for this project were produced on the wire EDM using the same tooth geometry macro from the actual wire-cut gear program, providing identical part accuracies and matching gear geometry. During EDM machining, these electrodes are "burned" into the solid blank, eroding the workpiece and leaving a finished gear impression requiring no additional processing.

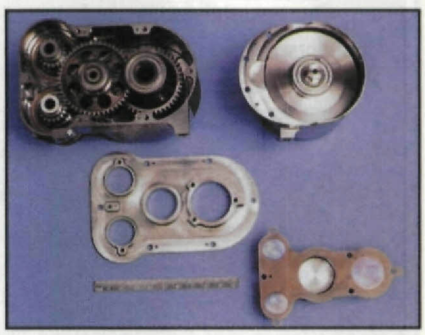


Fig. 1 — Airbag retraction actuator (ARA) for the Mars Pathfinder Lander.

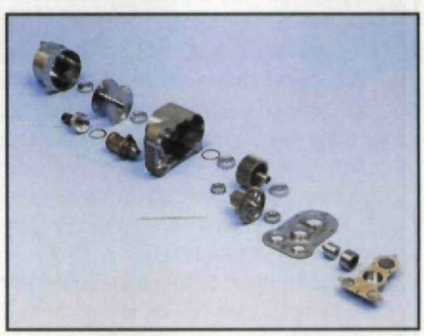


Fig. 2 — Exploded view of the ARA.

The Procedure

The decision to use EDM to cut the gears was based on several factors:

Workpiece Material—Initially, EDM was examined because of material properties. The gear loads will be quite high, and a tough, high-strength material was needed, so a maraging steel was selected. While this is a very tough material, its tendency to shrink during heat treating could affect the precise fit and mesh required for the finished gear assembly. Further, the final hardness specification would make any additional machining needed to correct any deformation cause by heat treatment very difficult. Using EDM allows the blank to be prehardened to its final specification and be machined "in the hard," eliminating any further processing.

Process Flexibility—Using EDM to manufacture gears allows for quick and virtually infinite adjustment of sizes and shapes of gear geometry without the need for custom hobs, shapers or broaches typically used in conventional gear manufacture. This degree of flexibility is especially important in any "cut-and-try" process of development.

Product Design—Besides having the ability to produce special gear assemblies quickly and economically, EDM can help steer the actual product design. Because the weight and size of components are primary considerations of space exploration, they must be as light and compact as possible. Unfortunately, some parts must be designed to be stronger and heavier than use specifications require merely to survive the rigors of their own machining and manufacture.

For example, sections of the part might be made thicker than necessary or have bosses added to facilitate tooling or clamping. The use of EDM on this part eliminated some of the tooling provisions typically required for holding the parts during conventional machining, because there is no physical contact of a cutter and workpiece. Material is removed with electricity instead of a mechanical cutter, eliminating the concerns of cutting pressures, clamping pressures, surface work-hardening, etc.

Since EDM is a "non-contact sport," part design and tooling considerations can be made without concerns for cutting pressures, setup rigidity, part wall thickness, etc. Part design can be optimized and manufacturing engineering can be simplified. This means that lighter, smaller parts can be made with more compact designs that help address the critical considerations of size and weight. In this case, a lighter launch and deployment vehicle will allow the use of a larger, heavier payload—the reason for the launch in the first place.

Product Testing—Since the gear hubs needed lightening, they were wire-cut with an internal hex bore which not only removed a significant amount of mass from the body of the gear hub, but also made dyno testing easier by allowing a common hex-shaft adapter to be used on all gears during speed and torque tests.

After careful analysis, engineers from the Spacecraft Mechanisms Engineering section of JPL concluded that gears made by EDM would fulfill all four of these criteria, and they then moved to contract that part of the project to an experienced EDM house.

JPL chose the Maroney Company in Northridge, CA. Maroney is a precision prototype EDM and machining facility with experienced EDM specialists, state-of-the-art machinery, a proven track record and the flexibility to shepherd through this kind of special project.

The Product

The wire-cut spur gear for the lander is made from Vascomax C300, has a .917" PD and a face width of 1 inch. The tooth form is modified and has a 25° pressure angle (see Figs. 1–2). Before machining, the blanks were prehardened to have a yield strength greater than 2000 Mpa (290 ksi). Using the vertical EDM, the remaining gear details were completed. Both processes (wire and sinker) provided gears of exceptional form and surface.

Extensive testing was done to analyze tooth form, surface condition and tooth thickness. For a 48-tooth gear, accuracies of the wire-cut parts had an average variance of only .00028" from a perfect tooth form. The parts produced on the vertical EDM have a .00028" taper across the gear face due to electrode wear, which resulted in a total average variance of .0005". These tolerances are equivalent to an AGMA class 10 gear.

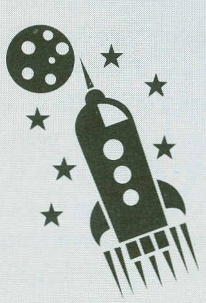
Concerns about recast, the very thin layer of thermally changed material remaining on the surface after EDM cutting, proved largely unwarranted. Maroney's experience and the use of a special anti-electrolysis generator with technology proprietary to Mitsubishi Electric (Japan) kept the finish and surface integrity well within specifications.

During these tests, it became obvious that making and testing custom

ROUGH LANDING

Here's your assignment, should you choose to accept it. Design gears to operate in a high-torque, low-temperature, dirty environment. They will be dropped from a vehicle traveling 13,645 mph and from 8,500 km in space. They will strike the rocky, low-gravity surface of Mars at approximately 50 mph and will bounce as high as a nine-story building as many as 15 times before coming to rest. The good news is the mechanisms have to work only once; the bad news is they *must* work. There will be no second chance.

Cushioning the landing and righting the lander are the tasks of the airbag retraction actuators and the lander petal actuators on the Mars Pathfinder Lander. Once on the ground, the airbags (made of a Kevlar-like material, Vectran, which may be ripped and deflated or still intact) have to be taken out of the way so the lander's solar panels can work. The lander itself, a tetrahedron roughly one meter in diameter, may land upside down or on its side and will have to be righted in order to function. EDM-cut gears are vital to the successful operation of both of these mechanisms.



gears by conventional means (hobs, master gears, etc.) would be both time-consuming and cost-prohibitive. While the EDM process is not necessarily applicable to everyday production gears, it proves invaluable for almost any experimental, R&D or specialty gear applications.

As with most experimental products, gears produced in this manner will cost more than the standard "off-the-shelf," garden-variety, but considering that, in the case of the lander, a multi-billion dollar investment will be over 140,000 miles away on another planet, gear failure is not an option. It simply *has* to work. Cost becomes a secondary consideration, with reliability being the primary concern. EDM has helped insure that.

Molded Gears

EDM has uses in more down-to-earth applications as well. A small (approximately 1" in diameter) helical gear to be used within the electric window mechanism of an automobile was needed. This gear needed to be quiet-running, long-wearing and have a natural lubricity because it was to operate within the auto's door panel and could not be easily lubricated. For this application, an engineered nylon was chosen to provide these characteristics.

If this had been a straight gear or spline, the mold cavity could have been machined using a wire EDM, but because the gear was helical, this became a CNC EDM application. A helical gear was machined from copper (slightly undersized to allow for the spark) and used as an electrode. The electrode was held in the spindle of a Mitsubishi CNC EDM equipped with a C-axis from System 3R that allows servo-controlled helical machining. Accuracies are virtually assured because the C-axis has a resolution of .001 of one degree and complements the servo resolutions of 0.1 micron or 0.000004".

Programming was very simple, requiring only a few lines of code commanding the machine head to advance in the Z-axis while simultaneously rotating the C-axis, literally screwing the electrode into the workpiece, eroding the material in front of it. After passing

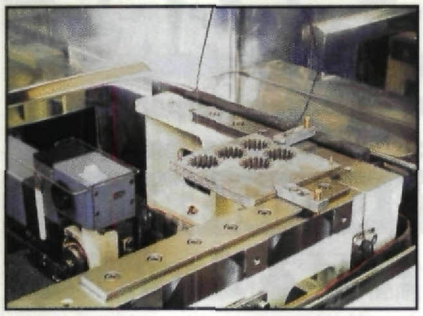


Fig. 3 — Stacked spur gears in an EDM.

completely through the mold insert, the final finish was obtained by using low current settings and a small circular orbit of approximately .0100 per side. The final finish required no further processing or polishing.

Manufacturing Engineering

The decision to mold these gears instead of machining them was based on the part material, the quantity required and the part tolerances. The decision to use EDM to machine the mold cavity was arrived at after evaluating the time and expense of conventional machining. The following are a few considerations and observations.

Machining Plastic Gears—Machining each gear was not an acceptable avenue because of the large quantity of gears required and the reluctance to use an expensive metal-cutting machine to machine plastic parts.

Both the quantity and material requirements favored the construction of a plastic-injection mold to inexpensively mold the production parts rather than machine them. With this decided, next came determining the best way to machine the mold cavity.

Conventional Cavity Making—The usual method of machining an internal helical gear would be broaching or internal shaping. Both of these methods were ruled out for several reasons:

1. Because the part was to be molded, part shrinkage must be taken into consideration when making the cavity. In this case, shrinkage was factored at 16%, and all cavity-making methods must allow for this. This shrinkage factor precludes the use of "off-the-shelf" broaches, increasing costs and extending deliveries. Shaping this detail would require special guides to be made, making an already expensive proposition even more so.

2. Helical broaching must be done on special machines capable of twisting the broach through the part similar to the way rifling in firearms is produced. Shapers must rely on expensive guides and cutters to produce an internal gear. Both methods were deemed too expensive.

3. Whether the detail is to be broached or shaped, all conventional machining of the workpiece must be done while the material is soft. When machining is completed, the insert must be deburred and polished, and then it must be heat treated, which can cause the cavity insert to shrink, expand or otherwise move and possibly distort the geometry of the gear.

Results

EDM was selected to produce the cavities for injection molding because:

1. An inexpensive copper blank can be hobbed and used as an electrode. Electrodes are made undersized and as long as the tooth form and geometry are correct, size and finish are easily controlled by means of orbiting offsets during machining.

2. This is a routing job for a C-axis-equipped CNC EDM, requiring only the helical electrode and a few simple lines of programming code.

3. Parts made on an EDM are typically burned "in-the-hard," eliminating any post-machining heat treating operations and the resulting potential for part movement due to thermal influence.

Short Run Production

The last application we will examine is one that EDM can address very well; the making of replacement or discontinued gears for repairs or older equipment. These "onesy-twosy" or small lot, short-run situations sometimes do not warrant tooling up on conventional equipment.

In this example, multiple spur gears are produced with a single cut by stacking up the prehardened, blank material and wire-cutting them from the solid (See Fig 3). Internal diameters and keyways are typically machined first, then the gear shape. Since all operations will be done in a single setup, perfectly concentric ODs and IDs are guaranteed. After programming and setup, an application such as this could run almost totally untended with very little operator intervention. A wire EDM machine equipped with an automatic wire threader could move from part to part autonomously and easily complete the project unattended during a overnight "lights-out" shift.

Again, EDM provides time and labor savings on an otherwise expensive task.

Summary

Obviously, we cannot conclude from these examples that EDM should always be used to prototype special gears, or that it should be used in all mold-making applications. There is, however, very strong evidence that EDM is a viable method for producing widely varying gear applications in a timely manner while reducing costs and eliminating secondary operations.

The scope of EDM gear use is very wide, ranging from the Mars Lander, a low-speed, high-torque application (0.7 rpm @ 100 ft/lbs), to the frenetic intensity of sustained, 1000 to 10,000+ rpms of a race car (see p. 34), to the relatively mundane task of occasionally raising and lowering a car window. These significantly different uses demonstrate the versatility and reliability of EDM-cut gears.

While EDM will never replace the traditional manufacturing methods of gear making, it has proven to be a worthy augmentation and a solution-finding process that has a valuable and rightful place in specific areas of gear development and manufacture. ✪

Reference:

Gillis-Smith, G. R. "Mars Pathfinder Lander Deployment Mechanisms." Jet Propulsion Laboratory, Pasadena, CA. 1995.