THE ULTRA-PRECISION FLAPPERS...

Did you know that controlled shot peening can increase the fatigue life of flapper valves by as much as an order of magnitude? Just what are flapper valves, anyway? A fair question. Unless you are involved in the design or manufacture of compressors, vacuum pumps or 2-cycle engines you probably would not know that we are talking about the very thin reed or flapper valves that control the intake and exhaust of these devices. Because flapper or reed valves are of necessity very thin and because they must be very flat, these critical reeds are amongst the most difficult type of parts to shot peen successfully. What makes it doubly difficult is that there are millions of them!

Most of us never see a flapper valve but they are all around us: in our refrigerators and air conditioners; in our lawn mowers, weed trimmers and chain saws; in the outboard engines that power our boats and the systems that cool our cars. When our homes were built, flapper valves were at the heart of the compressors that provided the air to drive the nails, to spray the paint and blow the insulation. Behind the dentist's chair, vacuum pumps create suction. In the ambulance and at the operating table, gas pumps provide the oxygen to sustain life. Flapper valves compress the air for your tires and for the bubbles in your aquarium. Research to develop more efficient and less polluting 2-cycle engines, to replace the traditional 4-cycle motors for passenger cars, is creating a whole new set of challenges to the technology of making reed valves that match the life requirements of those engines.

At Metal Improvement Company, Inc. (MIC) our core business is the prevention of metal failures and it was the implementation of this comprehensive technology, developed over almost 50 years of close integration with the aerospace industry, that led us to enter the manufacture of flapper valves. Simply put, we could make a flapper that delivered extraordinary fatigue life.

To quote D. N. Lal, Research Engineer at the Carrier Corporation: "The valve, suction or discharge, is one of the most critical components of a compressor. A flapper valve is required to have high flexibility to allow unrestricted fluid passage through the ports for achieving high efficiency and capacity of the compressor, but at the same time it is also expected to have enough stiffness to return back in time to seal the ports completely. The motion subjects the valve to severe cyclic stresses and strains. To make the situation worse, most of the valves have irregular geometry as unavoidable design requirements. This increases the possibility of localized stress concentrations and premature failure by fatigue" (Ref. 1). Note: a gas is considered a "fluid" in scientific terminology. Ed.

Few would dispute D. N. Lal's statement but it leaves the designer of a compressor (or engine, for that matter) with having to make a serious compromise between the efficiency of the machine and the life of the valve. The more the flapper valve flexes, the more passage of gas it will permit but the shorter will be the number of flexures it will sustain before breaking. It is incumbent upon the designer to seek a reed that will allow the maximum passage of the gas without breakage during the expected life of the other components of the compressor or engine at, let's not forget, a cost that is within budget.

The geometry of the reed is usually the first consideration and one over which the manufacturer of the valve has little control. Actually, designers are much better served when they include the manufacturer at an early stage of the design. Just being able to stamp out metal shapes is not sufficient: at
MIC we thoroughly understand all the factors that influence the life expectancy of a valve. For instance, the diameter of a mounting hole or the width of a slot, within obvious limits, may have little influence on the efficiency of a flapper but either can create difficulties for the valve maker that will significantly impact upon both the life and the cost of the reed. MIC’s engineers have extensive knowledge of materials; of stresses and strains (residual and applied — beneficial and detrimental); of how service life is affected by edge geometry, surface conditions, heat and corrosion; and of the influence of bending, torsion and impact loads. Because our specialty is flapper valves (not compressors or engines), input from MIC can be of great value to the designer, and is normally offered free of charge.

The ideal flapper valve would open fully and close totally in zero time — and last forever. The industry certainly is not there yet but evolving technology, based on a more complete understanding of the many phenomena involved, is taking the best valve makers ever closer. At MIC, we know that there are at least six areas that must be given critical attention:

* **Choice of material**
* **Quality of the “as stamped” edges**
* **Rounding of the stamped edges**
* **Removal of defects and detrimental stresses**
* **Depth and magnitude of beneficial stresses**
* **Flatness.**

Each of these items will be addressed in turn but it must be remembered that all are very much interrelated. For instance, maximizing #5 (depth and magnitude of beneficial stresses) in theory will allow the use of thinner steel (#1), so that the flapper may flex more and faster, but maintaining flatness (#6) might then become a difficulty that would compromise the flapper’s ability to close totally. Overcoming this type of difficulty is the province of a highly skilled valve maker and much has been done by Metal Improvement Company to address these areas.

Pursuing all of these details to the current state of the technology will produce a reed closest to the ideal. The extent of this pursuit is governed by the cost considerations of the application and the degree of efficiency that the designer wishes to achieve for his engine, vacuum pump or compressor. Designers need to be aware of all the options available to them and where those options can best be obtained. (Fig. 1)

### Choice of Material

There is much information published by the suppliers of flapper valve steels and it is not necessary to review it in detail here. High carbon strip is the choice for thin reeds and is supplied and stamped in the pre-hardened condition. Nickel-alloyed steel is usually used for thicker reeds and rings and may be hardened, ground and even lapped after stamping but before STRESS-LITE™ and shot peening. Stainless steel is indicated for applications where corrosion can be a problem, such as in the presence of air, water or steam, dilute organic acids, chlorides and sulphurous fumes. Even a mildly corrosive environment will always lower the fatigue properties, even of stainless steels, but the effect can be largely overcome by the introduction of the high residual compressive stresses that can be obtained by shot peening. Designers of marine engines should be aware that the chlorides in salt-laden sea air can reduce fatigue properties of even stainless steels by as much as 50%, if residual stresses are not properly controlled (Fig. 2, Ref. 2). High operating temperatures (over 500°F/260°C) will also aggravate both corrosion and fatigue.

### Stamped Edges

A fatigue failure will always initiate at the point of greatest stress concentration; sometimes at an inclusion in the steel but, in the case of reeds, almost always at a surface defect created by the stamping operation (Ref. 3). All subsequent manufacturing operations, i.e., edge rounding, removal of defects and the introduction of beneficial stresses, are mostly performed to eliminate or offset the edge imperfections from stamping. The technology of producing excellent flapper valves is totally tied to the technique of producing surfaces that are as free from crack initiation sites as possible. The importance of this will become increasingly apparent as we look at the subsequent operations.

**Rounded Edges Distribute Applied Stresses**

STRESS-LITE™ covers proprietary processes that have been developed to control edge radius, improve surface finish and to induce a high magnitude of residual compressive stress for increased fatigue life. The illustration is of a 2-cycle outboard engine reed, blanked out of stainless steel, which has a drawing requirement for a high compression on the tips and a lower compression on the balance of the reed. STRESS-LITE™ is used to process the entire reed to produce compressive stresses that measure as high as 99,000 psi. Addition of Shot Peening to the tips increases the surface residual compressive stress to as much as 132,000 psi.

<table>
<thead>
<tr>
<th>STRESS-LITE™ + Shot Peen = 132,000 psi.</th>
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<tbody>
<tr>
<td>STRESS-LITE™ only = 99,000 psi.</td>
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</table>

![Figure 1: STRESS-LITE™ and Shot Peening](image-url)
Effect of Peening on the time to failure of type 304 and type 347 Stainless Steels in standard SCC test.

**Figure 2: Stress Corrosion Cracking**

**Edge Rounding** Bending and torsional stresses are concentrated not only by notches (surface defects and/or sharp inside corners) but also at sharp outside corners. Therefore, even if we had a theoretically perfect stamped edge, it would still be necessary to use a process that will round the edge and distribute the applied stresses over a greater area. Here again, the quality of the stamped edge is key; to the degree that the as-stamped edge is smooth, less edge-rounding is necessary. Too much edge finishing, however, will produce a taper in the thickness of the reed on the sealing surface, so that the valve will not close off the port effectively. This may be difficult or even impossible to prevent if deep defects from stamping must be removed in narrow slots to avoid fatigue.

**Removal of Defects and Detrimental Stresses** There are a variety of processes available to the valve maker to, essentially, wear away the stamped edges and smooth out the stress-concentrating defects, even microscopic. All these processes are very time consuming (and costly) and have limitations, especially those imposed by the reed geometry. For instance, rough edges of narrow slots or small holes are very difficult to smooth out without losing dimensions on the more exposed surfaces. Starting with stamped edges that are essentially free of defects is paramount here. Also, the stamping operation itself introduces residual tensile stresses at the edges of the reed. Metal Improvement Company's STRESS-LITE™ processes have been specifically developed not only to round the edges but to reverse the detrimental residual tensile stresses into beneficial compression. (Fig. 3, Ref. 4)

**Depth and Magnitude of Compressive Stresses** Compressive stresses are introduced by MIC's STRESS-LITE™ edge-finishing process. These residual stresses are very shallow and of relatively low magnitude but, in many cases, are sufficient for the application, particularly if the stamped edges are near-perfect to start with. Shot peening will introduce comparatively much deeper residual compressive stresses and of a magnitude approaching the yield strength of the steel. It does so by indenting the surface (microscopically, in the case of flapper valves) so that the compressive stress is created in the subsurface fibers which can now be thought of as trying to push the indentation back out again, creating the residual or self stress in beneficial compression. It has been very well established that neither fatigue nor stress corrosion cracks will initiate or propagate in a metal that is in compression.

As far as fatigue is concerned, the higher the magnitude of residual compression, the higher the fatigue strength and therefore the longer the life of the reed. Application of this principle will permit the design of thinner and therefore more efficient flapper valves, that will open faster and open more, while still maintaining the required life. In practice, shot peening very thin reeds is not an easy accomplishment and there are two interconnected concerns: distortion and internal tensile stresses. Both are governed by the depth of the compressive stress layer below the surface, which in turn is a function of the material hardness and the kinetic energy that is transferred to the reed by the shot. Remember, though, that we are talking here of depths of only a few microns or a few thousandths of an inch — and these must be controlled very precisely. By contrast, Metal Improvement Company actually uses a "controlled distortion" (Peen Forming) to produce the aerodynamic curvatures on aircraft wing skins that can be as much as 1 inch/25mm thick, 12 feet/4 meters wide and 90 feet/27 meters long (Refs. 5 & 6).

**COMPRESSIVE STRESSES FROM SHOT PEENING ALMOST EQUAL MATERIAL YIELD STRENGTH**

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To effectively shot peening flapper valves that may only be 0.006 inch/0.15mm thick while holding acceptable flatness tolerances, requires unusual techniques. At MIC, shot peening is our core business, performed at over thirty contract facilities throughout North America and Europe. We shot peened our first flapper valves over 25 years ago and delivered up to ten times more fatigue life. It was this success that soon led us to develop STRESS-LITE™ and then our ultra precision stamping process so that we could control the manufacture of the valves from stamp to finish (pardon the pun!) and produce a much better flapper valve than is normally expected in the industry. It is for all these reasons
that Metal Improvement Company is the exclusive supplier to many of the prime manufacturers of compressors, vacuum pumps and 2-cycle engines.

If you would like more information on MIC's expertise in the design and manufacture of precision flapper valves, please contact our Valve Division in Bloomfield, Connecticut, USA: Telephone 203-243-2220 or Fax 203-242-7292.

"The Ultra Precision Flappers" is based on a technical paper, by Buzz Ferrelli and John S. Eckersley of Metal Improvement Company, Inc., entitled "Shot Peening Applications in the Compressor Industry", presented at the 1992 Compressor Engineering Conference, Purdue University, Purdue, Indiana.

SERENDIPITY

In the process of making flapper and ring valves, we have developed some interesting and unusual skills and we can apply these processes to many other types of metal parts.

Ultra Precision Stampings Making the project of stamping valve reeds and rings more difficult, the carbon or stainless steel strip is pre-hardened to 48-52 HRC and the reeds must be flat to within 0.003 inch per inch (we will leave it up to you metric buffs to convert that one!). Thicknesses range from 0.030 inch/0.76mm down to 0.0035 inch/0.09mm in carbon and stainless steel. Some stainless rings are 0.050 inch/1.3mm but these are harder after stamping. Dimensional tolerances for normal metal stampings are in the +/-0.005 inch/0.13mm range. To be able to stamp out the finest flapper reeds, we regularly hold dimensional tolerances of only ±0.0001 inch/0.03 microns. There are not many types of stampings that require this degree of ultra precision but if you have some that fit the description, we know best how to make them.

Ultra Precise Edge and Surface Finishing We developed the STRESS-LITE process to finish flapper reeds. After that, most everything else was relatively easy. Perhaps some examples will help you identify problem areas in your manufacturing that our expertise could correct.

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HELICOPTER TENSION STRAPS ARE EDGE FINISHED AND SHOT PEELED

Every time the Space Shuttle flies, the fuel is pumped by turbine blades that are peened and then finished by STRESS-LITE (note that this is the reverse of our usual approach of peening after STRESS-LITE). We are required to put a 0.0003 inch/8 microns radius on the edges of the firtree root of each blade! What's more, we can measure it . . .

The bar chart shows the performance of a suction valve for which field failure data have been statistically related to a low cycle/high stress regimen, thereby permitting accelerated life testing. The suction valve is used in an air conditioning hermetic compressor.

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<tr>
<th>Cycles</th>
<th>As stamped</th>
<th>STRESS-LITE</th>
<th>STRESS-LITE &amp; Shot Peen</th>
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<tr>
<td>0</td>
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<td>45M</td>
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<td>60M</td>
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<td>192M</td>
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Figure 3: LCF of Suction Valve, in Three Conditions
By contrast, we put a 0.015 inch/0.38mm radius on the edges of the slots on rotors for hydraulic vane pumps. The largest rotors weigh about 25 lbs. (10 Kilos) and are carburized and hardened to 60-62 HRC before we radius the edges.

Here is a really tricky one. Helicopter blades are held in place by a pack of thin 0.014 inch/0.35mm stainless steel laminations that twist and bend as the blades rotate. Metal fatigue is a major concern and, at MIC, we have developed a STRESS-LITE™ process to round the edges so as to distribute the stresses — and then we shot peen them. What’s so tricky? Each lamination is in the shape of a Y, with about 20 inches/500mm between the arms and 50 inches/1270mm in over-all length. Remember that they are only 0.014 inch thick and that they must remain FLAT!!

Just one more example. Machining airfoil shapes into impellers and blisks for jet engines is not an easy task, especially as very smooth surfaces are required for engine efficiency. STRESS-LITE™ has been shown to be ideal for smoothing out the inevitable machine marks without creating distortions. See us also for finishing Powder Metal parts of all kinds.

If any of these examples of surface finishing sounds interesting, remember that STRESS-LITE™ could be performed at any of the 30+ Metal Improvement Company facilities near you.

Peening of Ultra Thin Parts The US Military Specification that controls the shot peening of metal parts does not recommend peening parts that are thinner than 0.009 inch/0.23mm. Yet, at MIC, we have successfully peened flapper valves as thin as 0.006 inch/0.15mm and increased their fatigue life by many times. We have peened coil springs with a wire diameter of only 0.010 inch/0.25mm and totally eliminated a stress corrosion cracking problem. (Just in case you are thinking that we only shot peen little bitty parts, we have peened ammonia storage spheres that are 60 feet/20 meters in diameter, also to prevent stress corrosion cracking.)

John S. Eckersley, Editor.

How can we help you?

If your interest is specifically flapper or ring valves, this is the address you need:

Metal Improvement Company, Inc.
Reed Valve Division
98 Filley Street
Bloomfield, CT 06002, USA.
Tel: 203-243-2220/Fax: 203-242-7292

If your interest is more general, please contact our Technical Services Manager at any of the over 30 MIC plants in the principal industrial centers of North America and Europe or at our Corporate Offices either in the USA (Telephone 201-843-7800/Fax 201-843-3460) or in the United Kingdom (Telephone (44) 435-866022/ Fax (44) 435-866024).

You may also just mail back the Reply Card attached. Thank you.
REFERENCES
3. Dusil, R., "On Blanking, Tumbling and Shot-Peening of Compressor Valves," Proceedings of the 1978 Purdue Compressor Technology Conference, Purdue University, West Lafayette, Indiana, USA.
4. Unpublished chart, Carlyle Compressor Company, Syracuse, New York, USA.