

TECHNICAL ASPECTS OF SHOT-PEENING MACHINERY AND MEDIA

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When Herbert ¹ experimented in 1926 by pouring 3 mm dia. steel balls down a speaking tube on to a steel specimen contained in a metal biscuit tin, he could not have foreseen how far reaching his work would be. This idea of mechanical hammering was basically correct.

From these early experiments of peening has grown a whole vast area of an industry that has warranted over the years the attention of scientists and academics on the one hand and specialist engineers on the other.

The first essential for shot-peening to exacting standards are acceptable media of which today there is a wide choice.

Chilled Iron Shot - Chilled iron shot is a cast material. It is manufactured by melting suitably graded iron in a cupola, and at a critical temperature, pouring or projecting it into a quench tank. By these means the metal is broken up in flight and "shocked" by the water as spherical shapes.

The largest percentage are round; many are pear shaped, elongated and worm-like. As would be anticipated many particles contain incipient stress cracks. Screening and grading eliminate a great deal of the unwanted miss-shapes and tailings. Despite any shortcomings, chilled iron shot has two valuable assets, it is cheap and remarkably hard; usually in the order of 700-1000 V.P.N.

Chilled iron shot failed as a peening medium because of its virtue, the very hardness, resulted in rapid fracture and broken shot cannot be tolerated in a shot peening operation.

Steel Shot - Made by a similar technique as chilled iron shot, except that it is melted electrically, steel shot was introduced commercially in the late 1950's. The raw material is steel scrap, but to produce a high standard product this is very carefully selected for general use but peening quality is usually double and classified to ensure a better sizing standard and the removal of surface scale. All steel shot is produced to a range of sizes and subject to accepted grading standards.

The hardness figures of standard steel shot in Europe, and the United States are between 350-500 V.P.N. but shot for peening purposes has been satisfactorily produced as high as 665 V.P.N.

Cut Wire Shot - Cut wire is, as its name implies, wire cut into the form of pellets. Each pellet is cut with the length equal to the diameter. The single most important point is that the wire from which the pellets are cut should be of the recognised standard.

With specifically drawn steel wire, because of its manufacturing methods the

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product is free of latent imperfections such as incipient cracks, blow holes etc. In addition, each pellet may be said to be identical and uniform. Drawn virgin wire is a costly material and most wire used for cutting pellets is usually that which may have been rejected for minor superficial defects on the surface or slight inconsistency in the diameter. The wire is of high quality and whilst the quality may fail on these points as wire for the original purposes, it adequately meets the standard for shot-peening.

Obviously in pellet form, cut wire is unsuitable as a peening medium and requires to be conditioned. This entails processing the medium in a suitable shot blast machine when gradually the edges are rounded off to form a spherical shape. Glass Beads - From the point of view of a man-made mass produced object the glass bead is nearer to perfection than any other abrasive. Unlike metal shot which often includes pear shaped and other misshapened particles, glass shot keeps closely to a spherical form. Even the finest size maintains a degree of uniformity of shape.

The specific gravity of glass is one third of that of cast iron. In effect this implies that the medium may be picked up quickly into an air stream and rapidly accelerate. The almost perfect spherical shape assists in rapid movement though the feed pipe and the particles theoretically keep closer to the air speed than heavier metallic particles. This is one of the problems with air operated blast plants in that the frictional losses are high due largely to the pulsations of the air and the erratic movement through the supply tubes. The problem with glass beads is the loss of energy immediately they emerge from the nozzle and hit the air barrier. This will have an immediate and dramatic effect up the shot stream and the speed is reduced considerably in consequence. When using beads it is necessary to reduce the nozzle distance to 50 to 90 mm in order to lessen the loss of kinetic energy. In shot peening operations assistance can be gained by an increase in bead size and increasing the air pressure.

Ceramic Beads - Of recent introduction and produced to a very high standard and with a good resistance to breakdown, ceramic beads may find a ready acceptance in shot-peening. Made in sizes from 0.20 mm to 0.60 mm. Niku Lari² investigated the medium and his conclusions suggest that ceramic beads are comparable to steel shot in peening operations.

Stainless Steel Shot - Made by techniques similar to cast steel shot. A more expensive medium and great care must be exercised to ensure that all the fabric lining of a blast machine is fully protected to prohibit the stainless quality of the shot be impaired by ferrous contamination.

ERVIN SHOT TESTING MACHINE

This machine is modelled similarly to an airless blast machine, having a throwing wheel, a target and a recirculating device which rotates around a common centreline. Shot durability is determined by the number of impacts against the anvil that are required to break it into an unusable state.

PNEUMATIC SHOT PEENING SYSTEMS

There are three systems of using compressed air for shot peening purposes, in which the shot is projected from a blast nozzle.

- 1). Induction - syphon method.
- 2). Induction - gravity method.
- 3). Direct pressure.

1). Syphon Induction method is one in which the shot is aspirated to the nozzle. The method is uncomplicated and lends itself readily for use in hand cabinets. (Fig. 1).

The only claim that may be made is the simplicity of the system that permits constant uninterrupted working.

The one real objection is that most installations do not incorporate shot cleaning and shot grading which in the case of shot peening would not be tolerable. It is true that many parts requiring peening are ground and hardened and are in the finished state. In consequence they are classed as clean, so there is little

possibility of contamination of the shot, but all abrasives break down, (particularly glass beads, which is a popular medium for use in this type of machine) and this fact which has been emphasised continually is not tolerable in shot-peening. Shot cleaning and separation is just as important in shot-peening as it is mandatory in specific blast cleaning in the U.K.

2). The Gravity Induction - This system offers improved efficiency, with the shot being elevated above the point of usage, from there being permitted to free fall to the nozzle where it is energised by the compressed air. This is a neat method of providing continuous operation by elevating the shot in the recirculation system. The essential method of incorporating screening, grading and cleaning may be included.

3). Direct Pressure - This system is the most universally used. It is based upon the use of a pressure vessel (Fig.2) in which the shot is fed under pressure to the nozzle. A metering valve is incorporated in the system to adjust the volume of abrasive into the air stream. There is a precise balance between the volume of shot and the bore size of the nozzle. The value of this system is in the adjustments that may be made positively to the air pressure. The pressure vessel as a unit may be incorporated into hand cabinets and blast chambers.

For flexibility, the direct pressure method is superior to other methods. Every type of shot may be used with equal ease. Pressures are easily adjusted, nozzle distance and angle of impact may also be varied. The use of a nozzle permits the shot stream to be directed precisely. The weakness in the system is the uncontrolled method of feeding the shot via the metering valve. This is a problem which is being investigated at the present time and no doubt a great deal of the inaccuracy will be removed when the answer is found.

Wherever possible the nozzles should be mechanically controlled. They should be located at the correct distance, with the precise angle and with exact speed of movement. The machine should also be fitted with a timer so that the duration of each peening operation is carried out with precision. This does not eliminate the necessity to incorporate means of keeping a constant shot condition. All shot peening machinery should be fitted with graders to ensure a consistent standard of shot. Broken shot must be removed, so too should shot which is undersize. With small air operated plants it is difficult to fit shot replenishers, but where the consumption is sufficiently high they are essential.

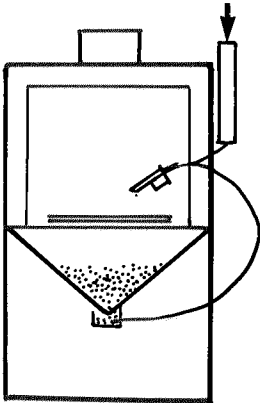


FIG. 1

Syphon Type Hand Cabinet

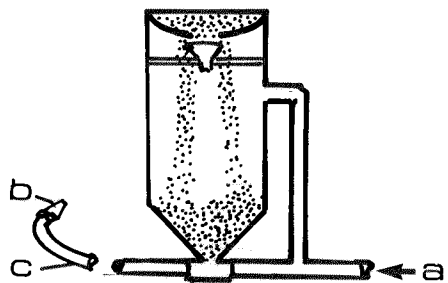


FIG. 2

Direct Pressure Type Shot
Blast Unit

TARGETING

The compressed air method of shot-peening has as its main attribute that of flexibility. Nozzles may be positioned precisely, and directed on to an area with the necessary accuracy. Areas of stress concentration such as fillets, grooves, shoulders etc. are typical of where the nozzle may be "targeted" with precise accuracy. Masking by means of rubberised tape over the non-stressed area is often a satisfactory way of limiting the effect of the blast.

Before any shot-peening operation is carried out the workpiece should be critically examined as to how it should be processed. The angle of the nozzle to the area requiring treatment; the pressure required; the size and type of shot and the distance of the nozzle. Shot emerging from a nozzle opens out and radiates from the tip and the concentration of shot will be the highest in the centre or core of the jet of shot. This is the "hot-spot".

Whenever a cylindrical component is required to be shot-peened, care should be taken to relate the "hot-spot" to the point of impact and not to overvalue the peripheral blast. For example a 50.00 mm wide blast when measured reveals a core concentration of 15.875 mm. The traverse or helix should be based upon this figure and not on the 50 mm overall width of blast (Fig.3).

Blast nozzles are often overlooked and undervalued and should be chosen carefully. The length should not be less than 200 mm, for a long nozzle will provide a greater concentrated core of shot in the blast stream - a necessary feature of good shot-peening.

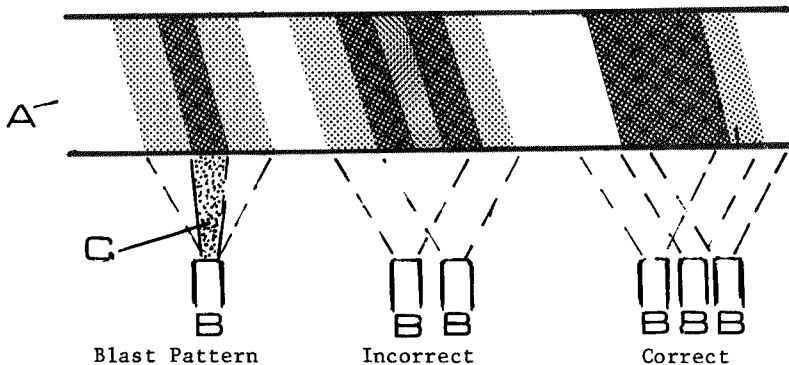
CENTRIFRUGAL SHOT PEENING

PRINCIPLES OF WHEEL DESIGN

As with other forms of shot blasting the original ideas of projecting abrasives by means of centrifugal action were those of Tilghman*, who took out patents in 1870. The patents covered two distinct methods, one of which was to feed the abrasive by gravity on to the wheel blades where it was energised by the force of impact. This was referred to as the "Batter wheel". The second patent was a method of feeding the abrasive to the centre of the wheel and it could be said that it is from this that the present types of "slider" wheels have been developed. Tilghman's wheel was designed to project the abrasive over 360 degrees and some time was to elapse before a wheel was evolved that had directional control of the abrasive. This characteristic was to prove invaluable in applications of highly technical merit. An early form of this was fitted with eight flat blades situated between two side plates. It is normal with this type of wheel to feed the shot by gravity through a tube to the core of a stationary control cage onto the blades of the wheel (Fig.4). It is the control cage, as its name implies that determines the direction in which the shot is thrown.

* Tilghman. B.C. First British Patent No. 2900 - 1876

FIG.
3



As the shot leaves the wheel it forms a configuration wherein the highly concentrated area is again referred to as the "hot-spot" (Fig.5) It is in this area that the shot-peening work is performed, as the concentration is highest and the angle of impact at the optimum. The control cage may be adjusted to suit individual components so that the "hot-spot" is at the precise peening point. The control cage will in time wear and in consequence the "hot-spot" will move off the workpiece. Immediately this occurs the shot peening operation is suspect. These are the principles which control a centrifugal shot-peening operation.

The original double sided wheel permits the greatest control over the shot stream. The method of blade fixing however limits such a wheel to a single direction of rotation. This was overcome by the introduction of a wheel which dispensed with blades and used instead a set of specially designed tubes. Blast wheels have been generally designed for blast cleaning purposes and not for shot-peening. They are designed for general purpose use, not with any special application in mind. There may well be room for more research into the design of blast wheels, especially with the growing demands for shot-peening. Whatever the diameter of the blast wheel the volume of shot thrown is directly related to the energy consumed. An increase in wheel speed will produce an increase in shot velocity, but with a decrease in volume. Slowing down the blast wheel will have the reverse effect (increasing the volume of shot at the expense of velocity) (Fig.6.)

The generally accepted speed for a blast wheel 508.00 mm in diameter is 2250 r.p.m. Wheels vary in diameter and speed and the criterion is the relationship between these factors and a proposed application.

BLAST WHEEL DESIGN - Observations suggest that blast wheels are arbitrarily designed with the commercial aspect as the dominant factor. Variations are introduced to be distinct and technical considerations are often not the prime motivation. The standard wheel, basically the original design, has been produced world wide, with slight variations in outline. This is a well balanced design and fitted into a suitable housing, rotates with the minimum of turbulence. The efficiency of this wheel is revealed by inspection of the blades after a period of time when it has been throwing chilled iron grit. Because grit hugs the surface of the blade, a tracery is left which reveals that the movement down the blade is exactly central. Open sided wheels are designed with a side plate which requires the blades to be held in position by the one edge (Fig.7). Most wheels of this type are designed to accommodate eight blades, yet there are similar wheels which are fitted with four blades. Whether eight or four blades are used, the movement of the wheel through the wheel housing must set up a more disruptive flow than a double sided wheel. The tracery of the abrasive in this case will have an offset fan pattern suggesting some movement toward the unshrouded side of the blades.

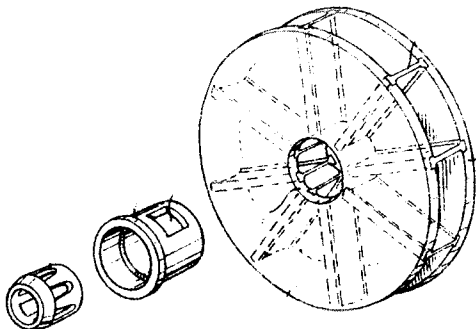


FIG. 4

Early design of
directionally controlled
Blast Wheel - illustrating
Impeller and Control Cage

This may be due to the wheel creating more air turbulence as it moves through free air. This does not suggest that this type of wheel is ineffective, for it has a proven record in general applications of cleaning and surface preparation, but it does suggest that in critical peening operations there may be room for more investigation on the question of effectiveness.

It cannot be claimed that blast wheels are aerodynamically designed. One wheel which may be so described however, is of a more recent introduction in which tubes replace conventional blades. In operation the air movement around this wheel is smooth and very little disturbed. Whether this is an improvement upon the basic double sided wheel is open to investigation. There is however, a fundamental difference in the flow of shot through the tubular blades especially when compared with the traditional flat blade.

When the shot has passed from the impellor through the control cage and enters the tubular blade, the passage is smooth and unrestricted. The shot flows down the tube in a concentrated form in a narrow path which results in a lengthened, but narrow blast pattern. The average blast pattern length when thrown from the optimum from this wheel is 1600 mm whereas the blast pattern length from a flat bladed wheel is approximately 1066 mm. This will indicate some appreciable difference in the two forms of blast wheels. Obviously in the case of the tubular wheel the shot in its initial travel down the tube is concentrated in a fine stream in the radius and opens out upon being released into free air. With a lengthened blast pattern there will be shot-peening applications where there is some distinct advantage and on the other hand, instances where the application may be superior with the use of a flat bladed wheel.

Some years ago Campbell* introduced a small wheel in which the design permitted the blades to extend beyond the periphery of the side plates (Fig.8). This was introduced with the object of conserving energy by eliminating the vee belt drive and direct coupling the wheel to the electric motor. Because of the load on the bearings of the motor, the size of blast wheel was limited, especially as a rotational speed of the blast wheel to be effective must be over 2600 r.p.m. Therefore an electric motor with a speed of 2800 r.p.m. was an obvious choice, together with heavy duty bearings to take the loading. Campbell abandoned the design after some extended period of use as the method was not considered to be a success. It appeared that the extended tips of the blades created turbulence resulting in a similar effect to blades of the single sided wheel, except that the tracery of the abrasive appeared to fan in both directions.

Blast wheels operate in a form similar to liquid pumps and yet perform with the function of a fan. Air is essential to the free flow of the abrasive through the wheel unit. Without air the abrasive will choke and fail to flow except in a minute quantity. The volume of shot thrown is directly related to horsepower (Fig.9). Blast wheels are usually driven by electric motors by means of multiple

* Campbell J.A. late of St.George's Engineers Ltd. & of Central Gauge & Tool Co.

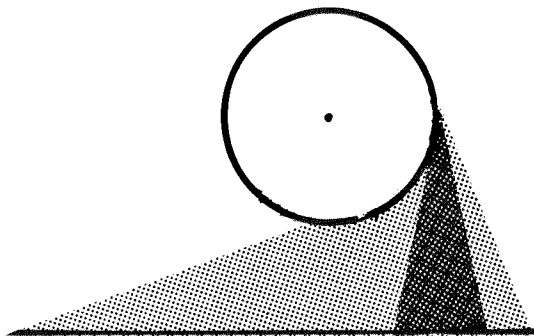


FIG. 5

Illustrating the "Hot-Spot" of a Blast Stream.

rope drives which have the advantage in that the final wheel speed may be adjusted when necessary by variation of the pulley sizes. Wheel speed dictates shot velocity, a very important aspect of shot-peening. This is an opposite view to a fixed single speed unit, with a direct coupled wheel where often when speed variation is required, it is impossible to achieve. Sometimes this is necessary because the machine has been built down to size, and the ability to introduce a vee rope drive is prohibited. Centrifugal machines lack the flexibility of those of compressed air type, where for example the operating pressure may be as low as 0.0703 kg./sq. cm to as high as 7.03 KG./sq. cm. Any and every means which improve the versatility of machines incorporating blast wheels must be considered.

Wheel Blades - The range of blade designs is legion, all may have specific features which are purported to be essential. They are the part of a blast machine which is subject to the most severe wear and because of this are made of case hard iron alloy usually containing 28% chrome. Each set of blades is balanced to fine limits, but being of cast construction may contain very slight imperfections. These are often not discernable on visual inspection, but will be very evident in use, when the wheel unit may become out of balance.

The original design of a blade was flat with slightly lipped sides to protect the side plates of the wheel from wear.

Blades of forms other than flat have been introduced, some with convex and others with concave faces. A form of the latter was patented* in the pre-war years, although no particular claim was made for them except that the design permitted a thickening of the blade tip which helped to resist wear and increase the life of the blade. More recently a blast wheel was introduced for which it is claimed that a similar concave blade assists shot velocity (Fig.10). By coincidence a wheel introduced concurrently carried a similar claim for a blade with an initial curve in the opposite direction. The heavy wear exhibited upon the wheel blades when compared with other elements of the wheel unit suggests that the blades do most of the work and their design may in consequence be most critical to wheel efficiency. There is little doubt that the length of the blades are an effective part of wheel design, but it is questionable whether any curvature is significantly effective in shot velocities. This is especially so when consideration is given to the peculiar bounce of the shot during its passage down the blade.

The blast wheel introduced with blades of tubular form (Fig.11) may be fitted with blades of various lengths according to the application. Tubular blades have been made of hard chrome alloy; of ceramic and of plastic. All the blades, including those of ceramic, which had bores of superfine finish, displayed the same undulations upon the surface caused by the bounce of the shot as found on all other types of blades. This bounce is very pronounced and is often measurable, the initial bounce being the largest with progressively small undulations on the surface to the point where the shot leaves the blade tip.

* Spencer Halstead Ltd. - Patent No. 1003441

A wheel of more recent introduction* has blades of a completely individual design. They are designed in a "V" shape and are also wider at the tip than at the root. This has the effect of throwing a wide blast pattern. The normal speed of a 300 mm dia. wheel is 3000 r.p.m. and when used for shot-peening the speed is increased to 4500 r.p.m.

To illustrate the effectiveness of the blast wheel for shot-peening an example may be taken from an aircraft component. This was shot-peened to Almen gauge "A" to an arc height average of 0.283 mm with steel shot S230. The time taken was 9 minutes on a rotary table type machine. The blast was powered by a 15 H.P. motor.

CONTROL CAGE - As has been described previously, blast patterns vary with the types of throwing wheels. The patterns may also be affected by the shape and size of the aperture in the control cage. Generally openings of square and rectangular form are favoured, though triangular openings and offset openings have been used, and in the case of the tubular bladed wheel half round openings are effective.

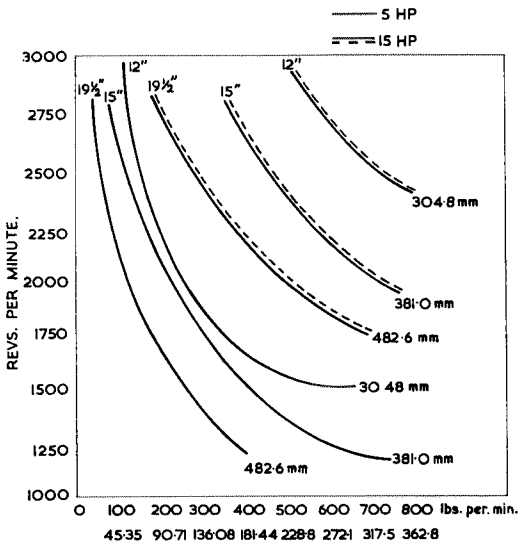
The opening, or aperture, of the control cage determines the length of the blast pattern and to some degree the size of the "hot-spot". (This term is used because when testing a blast pattern with a sheet of mild steel, this area will be found to be slightly warmer to the touch).

Blast wheels do not have the same flexibility as compressed air methods and they can be wasteful in specific applications unless every care is taken in relating the blast zone to the workpiece.

The control cage is adjustable to enable the shot stream to be projected at any point in 360 degrees. For example if the control cage aperture is set as on a clock face at 12 o'clock the shot will be discharged at a point from 3 o'clock onwards. The illustration indicates the whole blast pattern, not the "hot-spot", for this must be checked and ascertained precisely by means of using a piece of mild steel sheet placed in a stationary position under the wheel.

FEED IMPELLERS - This component is often disregarded as one of no real significance. Impellers vary slightly in design but are basically the same. Two companies in the United States incorporate coned inlets in the designs and this seems to have the effect of stimulating the movement of a greater volume of shot through the wheel unit.

* Sampoh Co.Ltd., Tokyo



WHEEL SPEED vs. ABRASIVE FLOW.

FIG. 6

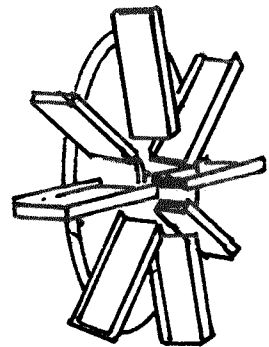


FIG. 7
Single Sided
Blast Wheel.

The impeller is closely related to the blast wheel in that it is made in a segmented form and the segments relate to the blades. In operation the shot is picked up by the impeller and passed through the control cage aperture onto the blades. This distance is small but the speed is so great and each segment is set slightly in advance of the wheel blades in order for the shot to alight onto the face of the blade.

In time the impeller will wear to a point where the shot will be ineffectively striking the inner leading edge of the blade. It is recommended that this critical component should be replaced when any part of its segments is worn more than 3.175 mm. The wear rate is high; one impeller will usually outwear two control cages*.

SHOT SEPARATION AND GRADING - With the advent of peening quality shot which has been selectively produced the problems involved with maintaining a higher quality peening operation have been considerably lessened. With all well designed blast plants the separation system receives as much consideration as the rest of the machine.

This section is situated at the head of the elevator, which raises the shot from the base of the machine for re-use. As the shot passes through the separator it is subject to the air drawn by the ventilation fan which pulls out the dust, scale and fragments of broken shot, and leaves the good shot for re-use. A well designed separator provides a curtain of shot evenly distributed in such a manner that good shot is not lost by being drawn out. This occasionally happens when there is a break in the curtain which disturbs the balance and permits at that point the ventilating air to pull good shot into the dust arrester.

It is pre-requisite of good shot-peening that the shot should be kept at all times as near to the recommended size standard selected for the particular operation. This requires the incorporation of a shot grader which is designed to select out the single size required. A shot grader is a sieving device in which there are tiers of selected wire screens.

SHOT REPLENISHING - Shot of course, is an expendable product, and its "life" in known conditions is predictable. It follows therefore that as the shot loses the optimum size for the peening operation, it is drawn from the machine and requires replacement. A replenisher located at the boot of the elevator or other suitable point will keep the volume of shot in the machine in a balanced condition. Signals from the shot hopper, situated below the separator, indicating the shot level, energise the shot replenisher and sufficient shot is added to maintain the necessary balance.

* Tilghman-Wheelabrator Ltd. Book of Running Instructions.

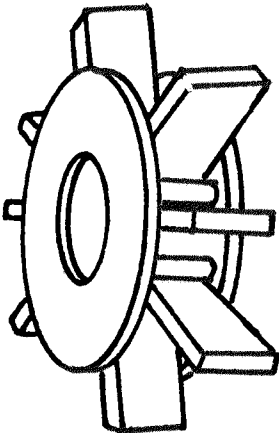


FIG. 8

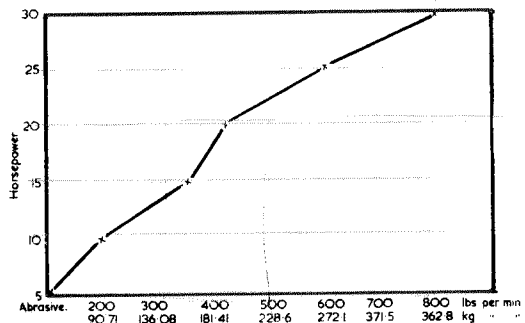


FIG. 9

THE ENERGY FACTOR - The centrifugal method of shot-peening is of higher efficiency than that of the pneumatic system. It lacks the flexibility of the compressed air method but has the ability to make much more efficient use of energy. The power used for a purpose built shot-peening machine will be relative to the demand, and usually this is in the area of 20 to 25 H.P. The register of efficiency is in the ammeter which indicates the volume of shot thrown by the wheel.

According to size, steel shot will lose velocity in comparatively short distances. This should give some indication of the cubic capacity of a blast cabinet

With a correctly engineered blast machine, the next essential is for sufficient air movement to ensure the cleanest atmosphere inside the cabinet during the shot-peening operation. Many components and workpieces are in their final stages and may be themselves scrupulously clean, and these will not present a problem. In the case of heavily scaled workpieces, such as leaf springs the air volumes must be adequate for the continuous removal of all dust and impedimenta.

INSTRUMENTATION:-

AMMETER - This instrument, referred to previously indicates the volume of shot being thrown. The meter should always show at the correct reading during processing and must be frequently monitored.

PROCESS TIMER - A vital instrument for in shot-peening operations, time is an important factor.

CONVEYOR SPEED INDICATOR - An essential instrument for the process period is the speed at which the workpiece passes through the blast stream.

WHEEL HOUR METER - A valuable addition to all peening machines. The meter records the actual period of time in which the wheel is throwing shot.

SHOT REPLENISHER CONTROL - Methods of maintaining the amount of shot in a machine may be either electrical or pneumatic. In each case, methods may be incorporated to indicate a shortage of shot in the system and the replenisher. These may be visual or audible or a combination of both.

MANOMETER - Incorporated in a dust arrester, this instrument indicates the pressure drop in the system, and in so doing assists in maintaining a constant air movement through the separator.

These are the main instruments. Manufacturers are constantly improving machine design and instrumentation is an area which is receiving attention. Computerised controls have already been incorporated in special purpose machines.

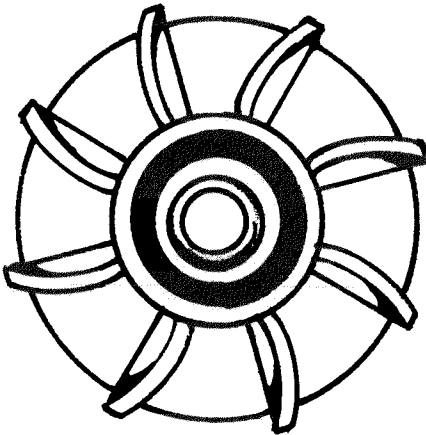


FIG. 10

Curved Bladed Single Side Wheel - Courtesy Pangborn Corporation.

Rotary Table Machines - For circular objects, a simple rotational method is often all that is necessary. (Fig.12). A wide variety of machines of this type are made. Whilst single individual table machines are used, many are multitable design. The tables vary considerably in size and a machine may have as many as 20 tables 250 mm in diameter, each machine being purposely designed for a specific product.

In line Conveyor Machines - Machines of this design in which an endless rubber belt is used to convey the work (Fig.13) have a good deal to commend them, especially items such as leaf springs. The belts are heavy reinforced with cotton ply to withstand the arduous conditions and are frequently pegged to locate the individual workpieces.

Diabolo Type Machines - Steel bars of sufficient length may be conveyed upon a machine of this type (Fig.14). This presupposes the bars or shafts are of clean line and are straight and have no upset areas.

Scroll Type Machines - Shafts which have an upset line, such as half-shafts which are flanged at one end may be satisfactorily shot-peened in a machine of this type. Due to the exposure to the blast stream the scroll requires to be made of a manganese steel, or similar abrasive resistant metal.

Carriage Conveyors - This is a method of conveying gears and crankshafts. The advantage of the system is that the components may be rotated as the carriage proceeds under the blast. The same system has been used for heavy locomotive leaf springs (Fig.15).

Stress Peening Machines - Both leaf and coil springs may be stress peened upon suitably designed machines. Machines of this type are the result of considerable expertise and design experience.

Peen Forming Machines - For this purpose, the machines generally used are of wide belt design with usually two or three down firing blast wheels, so that the special aircraft section is carried in the horizontal position. It would be remiss to overlook the many peen-forming machines of the compressed air type in which case the workpieces are processed in the vertical position.

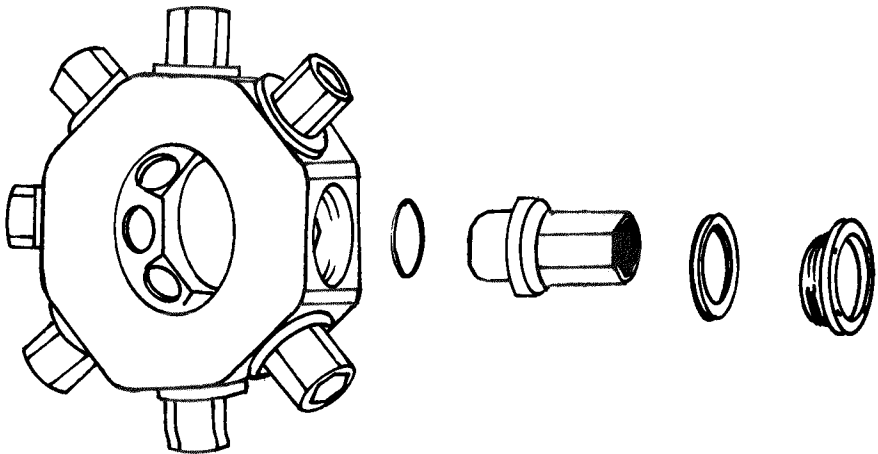


FIG. 11

Tubular Bladed Blast Wheel
Courtesy of Vacu Blast Co. Ltd.

FIG. 12

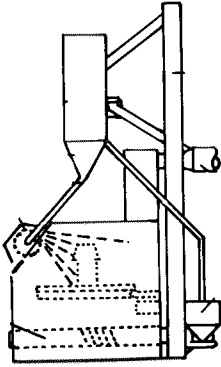


FIG. 13

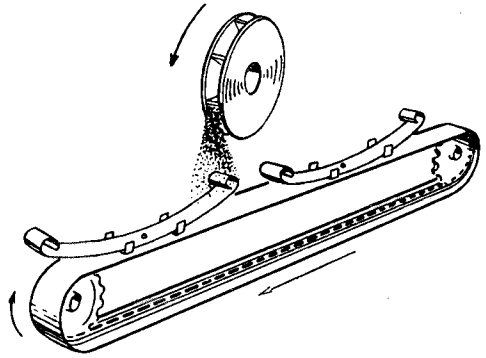


FIG. 14

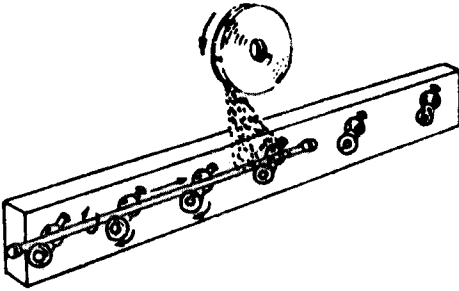
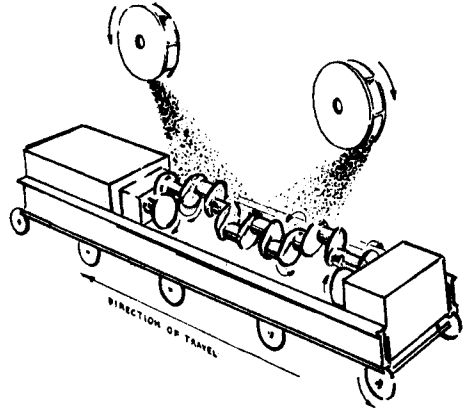


FIG. 15



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Mesures et Calcul de la Repartition des Contraintes Residuelles
Minibilles S.E.P.R. pour Traitement de Surface.

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Irvin Industries Inc.
Lockers Ltd.
Metabrasives Ltd.
Pangborn Corporation
Potters Industries Inc.

Sampoh Co.
Societe Europeene des Produits
Refractaires
Tilghman Wheelabrator Ltd.
Vacu Blast Ltd.
Vogel & Schemann A.G.
Wheelabrator-Alevaid