ABSTRACT

The shot peening process relies on multiple impacts of spherical media to a surface to achieve residual compressive surface stress. The flow rate of the media (lbs./min.) times the (effective) exposure time (min.) determines the number of impacts in a given surface area. To achieve consistent peening performance it is therefore necessary to continuously monitor the media delivery system. This can be achieved with inductive sensors for ferrous media or capacitive sensors for non-ferrous media.

Beyond providing a consistent process, these devices will also promote process optimization whereby desired intensity and coverage can be maintained and productivity can be enhanced.

The ability to accurately determine media flow rates then leads to the ability to accurately control the flow rate. Screw (auger) conveyors, miniature belt conveyors (Precifeed), pneumatically controlled grit valves, and magnetic valves can be employed.

KEYWORDS

Shot flow rate, shot flow controls, shot flow monitors, valves, MagnaValves.

Introduction

Shot peening is performed by impacting a surface with hard round balls, causing plastic flow and permanent deformation. The result is a residual layer of compressive stress which prolongs cyclic flexing component life and reduces cyclic fatigue and stress corrosion cracking. Complete coverage or denting of the surface is required to assure a uniform compressive layer.

The need for continuous flow rate measurement is further promoted with the latest edition of the U.S. Military Specification MIL-S-13165 Revision C. Section 4.2.5 Test Records requires that shot flow rate (and air pressure) be noted when processing the Almen strips.

While targeting and coverage tools, such as Peen Scan (1), are needed for set-up and post treatment inspection, in-process monitoring is necessary to assure consistent process control throughout the entire peening exposure time.

High flow rates (for air peening machines) can decrease shot velocity and thereby reduce peening intensity. Low flow rates can result in incomplete coverage and in some
cases promote surface damage due to the higher velocities available with lean flow rates. See Fig. 1 and Table 1 for intensity and flow rate correlation. Variations in flow rate during the peening exposure time can be detrimental and, therefore, it is helpful to continuously monitor the shot flow rate.

Older methods of flow rate control using a fixed orifice or adjustable media valves that are confirmed with a catch test do not provide the continuous monitoring needed for the process.

**Classes of Machines**

Peening machines may be divided into three classes, gravity drop, wheel type and air type. The gravity drop process usually uses a bucket elevator to lift the shot to the prescribed dropping height. Flow rate is easily monitored and controlled by regulating the elevator speed. Due to its basic simplicity additional methods of flow control are seldom used.

The centrifugal wheel, which has evolved from the blast cleaning industry, is used in peen forming and some high production volume, usually automotive, applications. Air type machines tend to be more versatile and better suited for lower production levels, usually found in aerospace applications.
Shot Flow Rate Monitors

Wheel peening machines. Wheel peening applications historically have relied upon wheel motor load current as a measure of flow rate. On some applications this may be acceptable, but active flow rate sensing provides some advantages.

Flow rate measurements that rely on motor current are generally limited to fixed speed wheels. This motor current, often referred to as "running-Amps", is one method of displaying the amount of work done to throw the shot and it is a good indicator of the amount of shot thrown. A typical ammeter may have a full scale range of 50 Amps (typically 16). Different size (diameter) wheels, different wheel speeds and different size or efficiency motors will affect the no-load and running-Amp values.

The ammeter readings are seldom converted to flow rate readings, but the implication of flow rate is there. The peening process is usually tuned to optimum (or acceptable) performance and the ammeter reading is noted for reference. As long as wheel speed remains constant and the wheel blades are in good shape the ammeter reading reflects the flow rate. But, care must be taken in using motor Amps as a process control. In comparing two or more wheels for performance the motor types must be identical. Different motor brands may have different efficiencies which are reflected in motor amperage. Blade wear and bearing conditions can change motor amperage. The running-Amps, for a constant flow rate, will change with motor temperature, stabilizing after several hours. Motor Amps also depend upon line voltage.

Wheels that are driven by belt and pulley have inherent losses that add to both no-load and running-Amps. Wheels capable of variable speed will use more current at higher speeds, even though flow rate is constant, since it takes more energy to throw the same shot amount at a higher velocity. Conversely, less shot can be thrown at higher RPM's. See Fig. 2. Therefore, for variable speed wheels both the motor speed (RPM) and flow rate (Amps) are required to define the process.

![Fig. 2. Wheel speed vs. shot flow rate](image-url)
Use of an inductive shot flow monitor avoids the above problems and provides independent measurement of flow rate. Flow rate information may be displayed either as a percentage of full scale capacity or in engineering units, such as pounds-per-minute. Not all flow rate measuring devices provide a linear convenience is negligible compared to process repeatability and higher degree of measurement resolution. Maintaining a flow rate that produces 13 Amps on a meter ranged to read 50 Amps full scale with 10 Amps for no-load is a challenge, especially since the running-Amps may decrease from 13 to 12 Amps due to motor heating. Use of a flow monitor with 1% resolution can greatly improve process control. Since it monitors flow through a sensor and ignores motor Amps, it can provide a more direct measure of the process.

Another benefit is the possible use of flow rate alarms associated with the flow rate monitor. These alarms are not influenced by motor current or its changes, due to factors like motor temperature. See Fig. 3.

Fig. 3. Shot flow display and sensor

Air peening Machines. Air type peening systems cannot use an ammeter for flow rate measurement (since there is no wheel motor current to monitor). Direct flow rate methods must therefore be used.

Most flow rate devices actually measure media density at a point after flow rate regulation. If the media maintains a constant velocity, then flow rate can be easily displayed. If the measuring point is after acceleration by air pressure, then variable velocities will affect calibration and a look-up table may be required.

Some Flow Rate Techniques

1. Optical
2. Acoustic
3. Capacitive
4. Inductive

1. Optical: Historically, optical approaches have been unsatisfactory since deterioration of the system components (sender, receiver, optical path) quickly reduces system sensitivity and accuracy.
2. **Acoustic:** Passive acoustic systems, similar to listening to flow rate with a microphone, degrade with hose deterioration and are also influenced by shot quality.

3. **Capacitive:** Capacitive flow monitors have been applied in air peening machines with limited success due to their narrow range of sensing. Most capacitive sensors are density measuring devices and are influenced by media velocity. The most common capacitance transducer, the unbalanced bridge method, may be operated in the constant velocity section of the blast machine and is therefore not responsive to air pressure or velocity variations. These sensors have an upper limit of approximately 30% solids/air ratio. They are well suited to glass bead and ceramic bead applications provided that proper sensor placement is available.

   For flow rate applications under 16%, the noise-type capacitive sensor can provide flow rate measurement; but care must be taken to consider velocity effects.

   A novel capacitive sensor from Tealgate, the capacitive-noise type sensors, works only in high velocity applications. This type of sensor does not provide an output signal for static conditions, such as a plugged sensor. The sensor, therefore, is located in the blast hose and its output signal must be corrected for velocity.

4. **Inductive:** For shot peening applications using steel shot, the inductive sensor can be used. Both single coil and multiple coil types are in use. The multi-coil transformer type, first used in the mining of iron ore, is described by the U.S. patent in the 1930's. A primary coil circles the flow path and it generates a magnetic field. A second coil, similar to the first, is placed over the flow path near the first coil. With no shot flow in the path the magnetic coupling between the coils is very poor and only a very small amplitude signal is derived from the secondary coil. When shot flow rate is established an "iron core" is introduced in the centers of the two coils and the magnetic coupling between the two coils is increased. The signal "transformed" from the first coil to the second coil is likewise increased and this can be displayed on a meter. While the technology is simple to apply, it suffers from poor signal-to-noise ratio and it does not maintain long term stability.

   An improvement on this scheme (2) uses a stacked column of shot whose height is a function of flow rate with an outlet flow rate equal to the inlet flow rate. A resultant measurement of the shot column, using the change in the coil inductance and displayed as a change in circuit current, is translated into flow rate information.

   Another approach, the inductive oscillator, involves measurement of either the oscillator amplitude or frequency. Since inductive proximity switches commonly use amplitude measurement, this was the earlier approach. This is simple to implement; but various shot sizes result in different responses and recalibration is occasionally required.

   Another development, a single coil oscillator inductive shot flow sensor, is based on frequency measurements. Sensors using this technology are available in sizes for both air and wheel peening applications. Since the sensor is actually a steel density measurement, shot flow rate is measured in a constant velocity zone. For wheel machines this is between the media flow rate regulating device and the wheel inlet. For direct pressure air peening systems, the sensor is located below the media regulator and
above the mixing chamber. The sensor can be used in venturi or suction type peening machines if the velocity (pressure) is kept constant. If various pressures are used, then a look-up table must be used in order to maintain calibration.

Since the magnetic properties of cast steel shot are different from wrought (cut wire) shot, a recalibration is necessary when changing media. Some recalibration may be required for different sizes of the same media, depending on packing densities.

**Shot Flow Control Mechanisms**

Shot flow rate controls can be divided into two classes, restriction devices and conveyance devices.

I. **Restriction Devices**

1. fixed orifice plates
2. mechanical valves
3. magnetic field modulated valves

II. **Conveyor Devices**

1. auger screw
2. micro conveyor

I. **Restriction Devices**

1. **Fixed orifice.** The fixed orifice is the simplest device in the first class. The orifice plate is often constructed with an extension wherein a hole of the same size is located as an identification aid. See Fig. 4. Fixed orifice plates provide constant flow rates provided that:

a. the media flow properties are constant
b. pressure above the orifice is greater than below the orifice
c. the air pressure differential remains constant
d. the orifice size remains constant
e. no air leaks are introduced.

![Graph of shot flow rate vs. air pressure](image)

*Fig. 4. Shot flow rate vs. air pressure in direct pressure system with fixed feed rate orifice.*
2. Mechanical valves. Mechanical valves provide the ability to operate at various flow rates without disassembly as required by the orifice plate. Mechanical valves used in wheel peening applications include dipper or clam shell valves and slide gate valves. These are generally operated by air cylinder for on/off action. The open position is often limited by a positive stop which is readjusted manually. See Fig. 5. In some applications electric drive motors are used to position the positive stop and this allows for remote setting.

![Dipper valves diagram](image)

Fig. 5. Dipper valves

Mechanical valves used in air peening are generally applied to direct pressure systems and are either air or electric actuated. The air actuated devices usually employ a large diaphragm to overcome the restraining force of a spring. See Fig. 6. In some cases the control air pressure is remotely regulated to provide variable flow rates instead of on/off action. Another valve concept, often called a pinch tube, has no moving parts except the flexible pinch tube. See Fig. 7. by applying a higher pressure to the outside of this tube it collapses and restricts the shot. The tube will eventually erode due to the capture of shot within the tube. Tube life is further decreased by excessively high air pressure.
Fig. 6. Mechanical media valves
Venturi type peening systems generally use an adjustment for regulating the aspiration air inlet to modulate the suction and hence the amount of media entrained into the flow stream. See Fig. 8. This is similar to a carburetor where the choke butterfly plate is used to modulate the vacuum. One of the problems with this arrangement is efficiency. The flow rate is determined by the amount of vacuum available to suck shot into the blast hose. To increase the suction the air aspiration inlet is reduced. This allows more shot to be entrained in the hose but with less air volume needed for conveyance. At some point there is too little air volume at a sufficient velocity to convey the shot and the blast hose either surges or, in extreme cases, shot flow may cease, causing blocking of the hose. Typical flow rates for induction type nozzles are 5-9 lbs./min. for 3/8" nozzle and 8-15 lbs./min. for 1/2" nozzles.

Another limitation to venturi type machines is the energy required to convey the shot from the shot hopper outlet to the nozzle. If the nozzle is located above the media carburetor, then energy is expended to lift the shot. This energy loss can be greatly reduced by raising the media carburetor above the nozzle level. Use of a bucket type
elevator for media transfer may be necessary to accomplish this. See Fig. 9.

If a pneumatic media recovery system is used care should be taken that the pressure differential above and below the shot supply does not interfere with media discharge from the carburetor. A large (compared to nozzle) vacuum from the dust collector may not be noticeable with a large head of shot; but if the shot supply gets low the shot may be held up in the hopper discharge. The aspiration air will travel up through the shot towards the dust collector and reduce or block shot flow rate. See Fig. 10. Choking the carburetor will increase the venturi nozzle suction and reestablish shot flow, but the correct action would be to reduce the dust collector vacuum to a lower level.
Another approach to venturi nozzle design is to place a mini-hopper, or funnel, directly above and attached to the nozzle. This alleviates the problem of dust collector backwash and relies on the nozzle design to regulate the flow rate. Flow rate will be constant as long as air pressure is constant and the internal nozzle parts are not eroded. This technique is also referred to as gravity-fed nozzles.

3. Magnetic valves. Peening machines using steel shot can be regulated with a magnetic valve. These devices do not have any moving parts. The valve is normally closed due to a permanent magnet. Applying power to the valve cancels the magnetic field and shot falls through the valve. These valves were first used for wheel applications and later adapted to air peening machines. See Fig. 11. In both wheel and air peening applications the valves can be either open loop or, by including an inductive sensor, they can operate in the closed loop serve mode.

![Fig. 11. Cut-away view of wheel peening MagnaValve](image1)

For direct pressure peening the MagnaValve is placed below the media hopper and above the mixing tee. Care must be taken that there are no leaks above the MagnaValve, since this backwash of air can levitate the shot. See Fig. 12

![Fig. 12 MagnaValve for direct pressure peening](image2)
When the MagnaValve is used in suction peening machines it acts like a fuel injector instead of a carburetor. See Fig. 13. This provides the advantage of allowing large amounts of aspiration at all flow rates and injecting the proper flow rate of shot as required. The servo loop controller is used to monitor and control flow rates without influence of air pressure changes.

![MagnaValve diagram](image)

**Fig. 13.**

II. Conveyance Devices

1. Auger feed. The auger screw feed, borrowed from the agriculture industry, is a simple mechanism capable of precisely metering shot. Its primary advantage is its ability to convey any granular media. It is easy to use with suction type air peening machines, but direct pressure systems require more elaborate construction.

2. Micro-conveyor. The Preci-feed precision feeder from Tealgate is a miniature conveyor with a depressed belt housed in a metal enclosure. It is suitable for all granular media and can be used with direct pressure or suction peening machines. It has a demonstrated accuracy and repeatability of 2% and is in use for glass bead peening and plastic media blasting for paint stripping. Plastic media, which is very low density, is notoriously difficult to control. The Preci-feed conveyor is especially suitable for this application.

**Combined Flow Rate and Velocity Measurement**

Wheel peening machines inherently provide shot velocity information, since the wheel speed (RPM) is known. Air peening machines provide another challenge. We expect to see nozzle shot velocity measuring devices incorporated into flow monitoring systems within the next two years. Two systems are presently under development. The first is useful for only steel shot and experimental data indicates a high degree of accuracy compared to a laboratory double rotating disc.

The second device, using a different technique, provides both nozzle shot velocity and mass flow rate information for any granular media. Laboratory models of this device
exhibit 2% velocity accuracy for glass beads. This technique is likely to see its first application in plastic media blast cleaning for stripping paint from aircraft. Later applications will be toward glass and ceramic bead shot peening.

**Conclusion**

If you can't monitor it, you can't control it. The direct and continuous measurement of shot flow rate is necessary to assure homogeneous processing. A variety of tools is available to accomplish the task.

**References**

(2) BIEHLE, WILLIAM C., "Apparatus for Measuring Flow Rate of Electromagnetic Granular Media", U.S. Patent 4,552,017.