GLASS-BEAD PEEN PLATING

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16. Abstract

Peen plating of aluminum, copper and nickel powders was investigated. Only aluminum was plated successfully within the range of peen plating conditions studied. Optimum plating conditions for aluminum were found to be:

1) Bead/powder mixture containing 25-35% powder by weight.
2) Peening intensity of 0.007A as measured by Almen strip.
3) Glass impact bead diameter of at least 297 microns (0.0117 inches) for depositing - 100 mesh aluminum powder.

No extensive cleaning or substrate preparation is required beyond removing loose dirt or heavy oil.

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PREFACE

The objective of this investigation was to find the conditions under which optimal peen plating could be achieved. This included modification of a NASA-GSFC furnished "Zero Blast N Peen" Machine and design of a spray nozzle and other related equipment.

Optimum conditions were found for plating aluminum powder. Copper and nickel powders did not plate within the range of conditions investigated.

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I EQUIPMENT

There are several components required to perform peen plating. The air gun, which does the actual plating, a power source for the air gun, such as a compressor, a vacuum reclaiming system which serves to remove the spent glass and metal powders from the cabinet, filter and then store them for reuse, and lastly the cabinet in which the plating is done. All of the components except the air gun, are commercially available.

a. Vacuum reclaim system and cabinet.

The spray cabinet is a 66.04 x 106.68 x 68.58 cm metal cabinet with a sloping top containing a small window so one can observe the inside. The spray cabinet is connected to a cyclone separator by a 108cm flexible tube. The material coming from the separator is stored in the tank below the separator. This assembly was made by the Zero Manufacturing Company, and designated as Model number BNPA-9. ARTECH modified the assembly by removing the bead feed mechanism that was on the bead storage tank and replacing it with an aspirator.

The bottom of the storage tank was fitted with an aspirator. Its location is shown in Fig. 1 and a detail in Fig. 2. This consisted of a 1.90cm I.D. flexible plastic tube 15.24cm long. The upper end was attached to the storage tank and the lower end was plugged and attached to a vibrator. A short length of 0.953cm O.D. thin wall stainless tubing was inserted about 2.54cm from the lower end. Directly oposite this tube, an air intake tube consisting of a 0.317cm O.D. stainless steel tubing was inserted. A length of 0.953cm I.D. clear flexible plastic tubing was connected to the larger stainless tube, which carries the bead mix to the spray gun.

b. The spray gun and its air supply.

The spray gun, except for the interchangeable exit nozzel, was made from stainless steel. The exit nozzle was made from tool steel and hardened. The following references refer to Fig. 3. The main body, D, is 2.54cm O.D. at its widest and 1.745cm O.D. at its narrowest. The narrow end had a 1.27cm hole 2.54cm deep to accept the exit nozzle. Three small set screws through the body held the nozzle. The wide end had a 1.93cm hole 2.08cm deep to accept Part B. Three small set screws through the body held Part B in place. A 0.952cm hole placed 1.587cm from the wide end served as the mix supply intake tube. This tube was a 0.952cm O.D. thin wall stainless tube soldered to Part D. The flexible mix supply tube connected to it. Part B was 1.93cm O.D. for 3.492 cm and

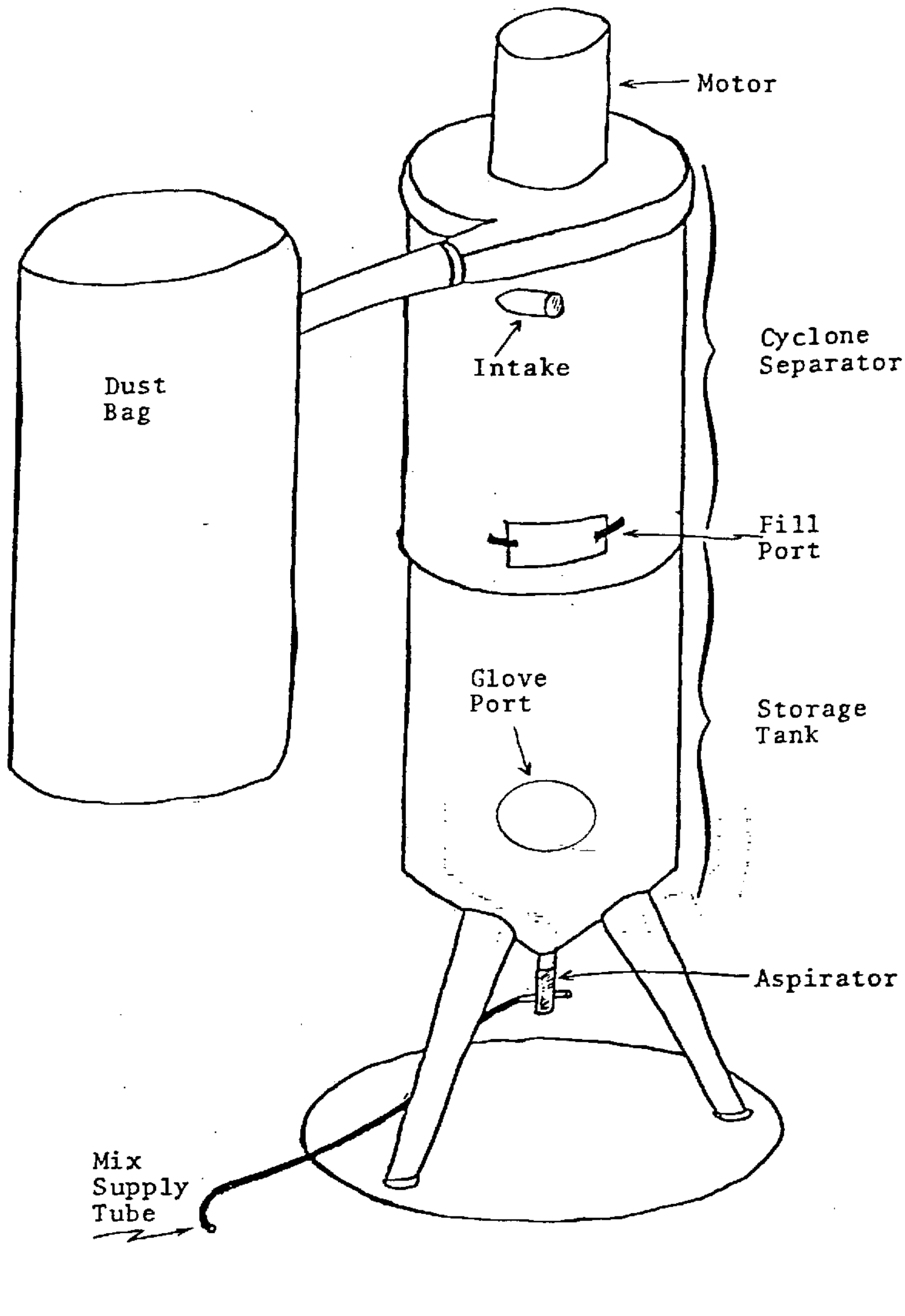

Figure 1. Vacuum reclaim system and storage tank.

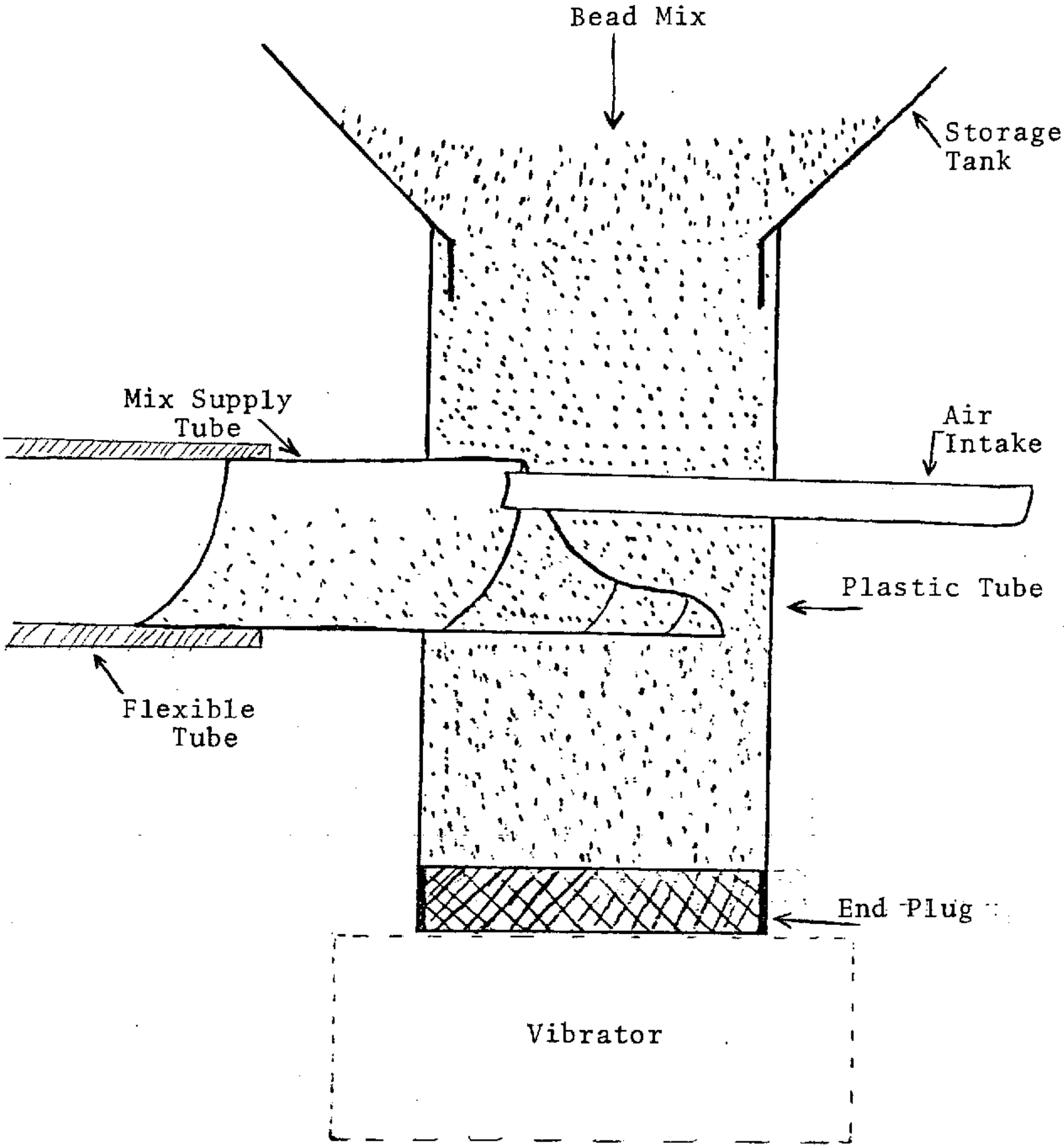

Figure 2. Detail of the aspirator.

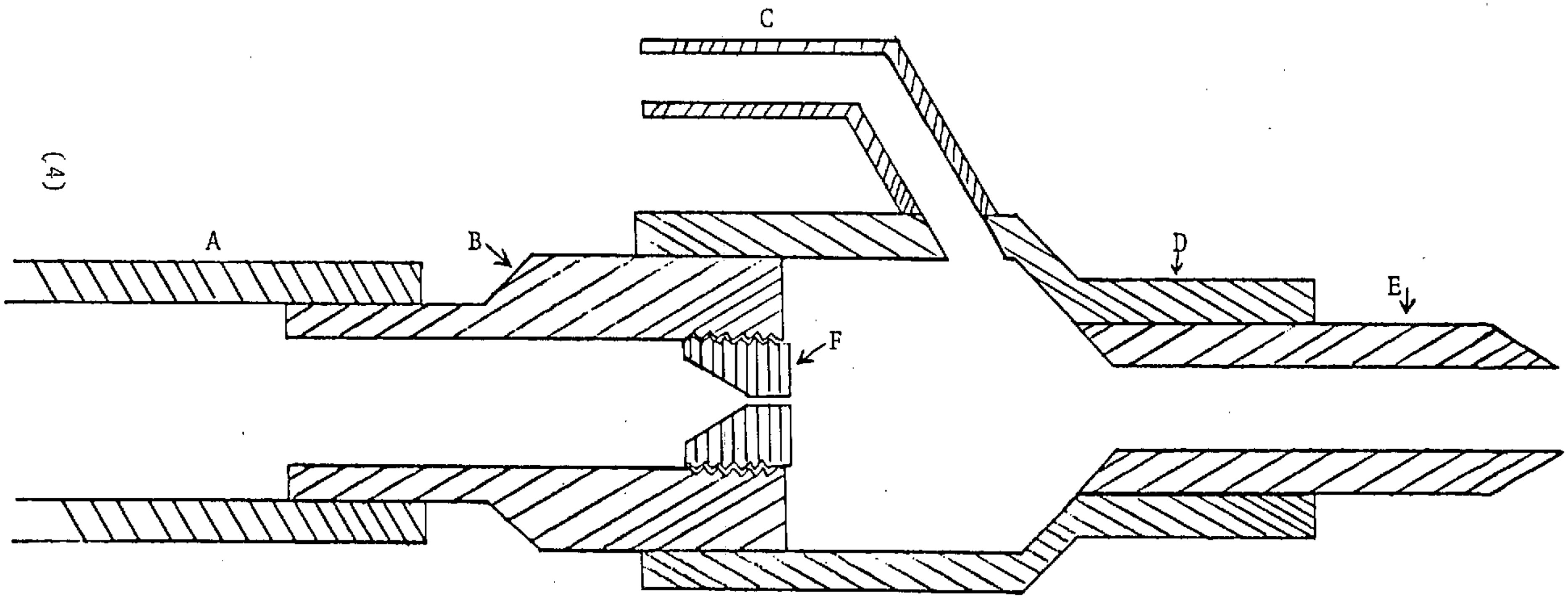

Figure 3. Detail of the spray gun parts.

Note: Dimensions are exaggerated for visual clarity.

A Flexible Air Supply Tube

B,D Stainless Steel Gun Body

C Mix Supply Tube

E Interchangeable Exit Nozzle

F Interchangeable Orifice

reduced to 1.109cm O.D. for 2.54 cm. A 0.635 cm hole was through it. The wide end had a 1/2-13 thread 1.27cm deep for the orifice plug. The reduced end had the flexible air hose clamped to it. The orifice plug was a cylinder threaded to match Part B. This plug was 1.27cm long. The orifice hole was through the center of the plug. Various sized orifice holes were tried, but all of the samples were made with an orifice diameter of 0.345 cm. The nozzle was 1.27cm O.D. by 4.762cm long rod with a 0.714cm hole. The positive pressure side of both the plug and nozzle were tappered inward with the tip of a 1.27cm drill.

The spray gun was powered by a Speedaire Model 3Z172 compressor. A 227.1 liter tank served as the reservoir. The compressor had a capacity of 10.4 liter/sec. The air pressure was regulated by a Hannifin 0-7.03 Kg/cm^2 (125 psi) regulator. The moisture trap is also made by Hannifin. Both the regulator and moisture trap were parts of the Zero Manufacturing Company's reclaim system. The complete air-flow system is shown schematically in Fig. 4.

c. Substrate transport and spray gun holder.

A transport was made to provide a constant substrate travel speed. This device was and "L" frame with a pulley on each end. To the center back of the frame was fastened a rotary shaft parallel to the pulley shafts. The "L" frame was 34.29cm long, 10.79cm wide and the lower tab extended 3.17 cm in front. Resting in the "L" frame was a smaller "L" frame. This acted as the sample carrier. The sample carrier had a string attached to one end. This string passed over one pulley then coiled once around the rotary shaft, over the second pulley and back to the other side of the sample holder. The rotary shaft was connected to a flexible rotary cable. This cable went out of the spray cabinet and was connected to a 5 r.p.m. reversible electric motor. With this arrangement the sample was moved at a rate of 6.45 cm per minute past the spray nozzle. The motor was reversed each time the sample carrier reached the end of its travel. This was done with two micro-switches and a reversing relay. The spray gun itself was mounted in front of the substrate carrier in such a way that nearly 15cm of the sample was covered in each pass. The gun was on a rack so the operator could move it up or down the 7.62cm width of the sample.

d. Peening intensity measurement.

To measure the peening intensities, an Almen Specimen Gauge was used. The Almen test strips were Type A and Type N. In use, the Almen test strips were fully covered and the arc height measured on the Almen Gauge. Both the Almen Specimen Gauge and Almen test strips were obtained from the Wheelabrator Corporation.

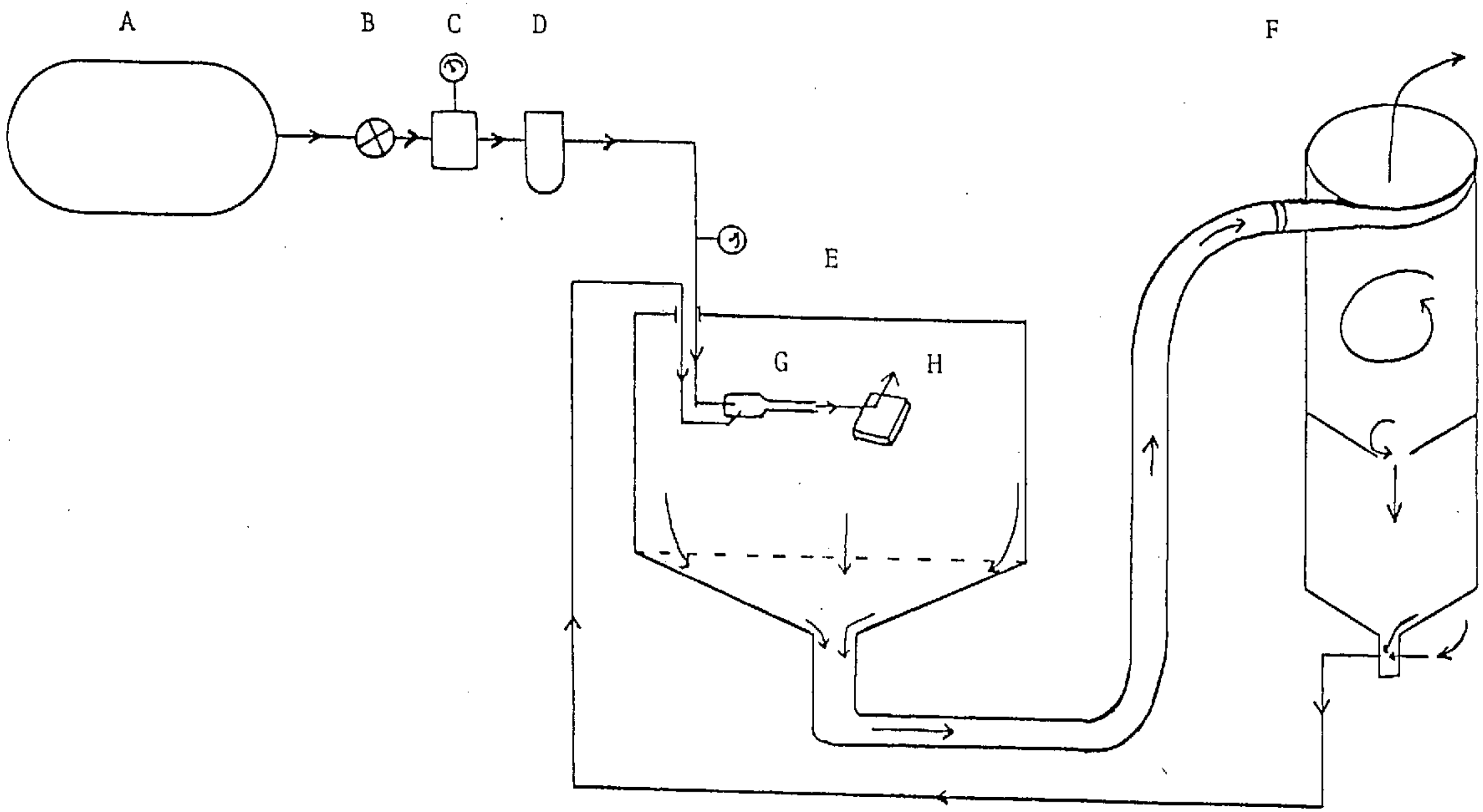

Figure 4. Overall air flow schematic.

A	Compressed Air Supply	E	Spray Cabinet
B	On/Off Valve	F	Bead/powder Recycling System
C	Pressure Regulator	G	Spray Gun
D	Moisture Trap	H	Sample

II MATERIALS

a. Substrates.

The substrates of aluminum, steel and copper alloy were 7.62 x 15.24 x 0.317cm plates. The aluminum was 6061 alloy, and the copper alloy was yellow brass. The magnesium substrate dimensions were 3.81 x 15.24 x 0.0762 cm. These strips were backed with 7.62 x 15.24 x 0.317cm aluminum plates. HK31A-0 was used for the magnesium alloy.

b. Impact beads.

The glass Ballontini impact beads were in three size ranges. Bead size A was 20-30 mesh, size D was 50-70 mesh and size H was 100-140 mesh. These beads have a silica content of more than 60%, and a specific gravity of 2.45-2.55. The minimum percent true spheres of sizes A, D and H is 60,60 and 85 respectively. As supplied, these impact beads have a maximum of 3% scored, broken or angular surfaces which would present sharp or angular surfaces when impacted.

c. Metal powders.

The nickel and copper powders used were of two size ranges: -100 mesh and -325 mesh. The aluminum powder was -100 mesh only. The nickel was commercially available pure and analysis showed it to be 99.55% nickel for the -100 mesh and 99.59% for the -325 mesh. The -100 mesh copper powder was 99.64% and the -325 mesh was 99.62% pure. Both the nickel and copper powders were supplied by Glidden-Durkee. The aluminum powder was 1100 grade -100 mesh and was supplied by Alcan.

III PROCEDURE

a. Substrate surface treatment.

Prior to peen plating, the substrates were stamped with a code number and then prepared in one of four ways.

1. The bead cleaned samples were sprayed with the size H glass bead. A peening intensity of 0.007A was used, and the exit nozzle tip was 0.5 inch from the substrate.

2. A 10.15cm diameter wire brush was used on a second substrate to remove the surface particles. The brush was attached to a drill press and the sample was hand held. When the metal surface appeared completely brushed, the brushing was stopped.

3. The third substrate was wiped with solution of methanol and acetone, 50% by volume each. This solution was liberally applied with clean paper tissue. After all visible traces of oil were removed, the substrate was placed on end and air dried.

4. The last substrate of each series was chemically cleaned. The brass, steel and aluminum were individually cleaned in an ultrasonic bath of benzene followed by acetone.

The brass substrates were dipped at room temperature for two minutes in Neutraclean (Proprietary - Shipley Company, Inc.) The aluminum was dipped at room temperature with agitation for two minutes in sodium hydroxide. The sodium hydroxide concentration was 20 grams per liter of water. The steel was cleaned in solution A for 10 minutes at room temperature, rinsed with water and dipped for two minutes at room temperature in solution B.

Solution A	85 grams potassium permanganate ($KMnO_4$)
	142 grams sodium hydroxide (NaOH)
	1 liter distilled water
Solution B	1 liter hydrochloric acid (HCl)
	1 liter distilled water

The magnesium was first washed with Ajax Cleanser in hot water and then dipped with agitation for twenty seconds at room temperature in 85% phosphoric acid, H_3PO_4. After the chemical treatment the substrates were rinsed in cold water, then in hot water and allowed to air dry.

After cleaning each substrate was sealed in a plastic bag to protect the clean metal surfaces from dust and oils.

b. Mixing powders.

Glass bead to metal powder mix ratio was determined by weight for the aluminum powder. Mixing aluminum powder by volume was not carried out because both the glass bead and aluminum powder tended to settle, thus changing their respective volumes. Metal powders of nickel or copper were also mixed by weight. However, the relative densities of the glass bead and metal powder were used to determine the correct mix ratio by weight to get a given mix ratio by volume.

c. Mix ratio monitoring.

Since the system recycled the mix, a method was found which would allow the mix ratio to be monitored at any time. However, this was not done for copper or nickel.

A sample of the aluminum powder and bead mix was weighed. The aluminum powder was dissolved in a concentrated solution of warm sodium hydroxide. When there were no visible traces of aluminum, the sample was rinsed in water to remove the sodium and aluminum hydroxides. After drying, the sample was again weighed. It was assumed that any loss of weight would be due to the removal of aluminum. This loss was then converted into the percent mix ratio.

d. Mix flow rate.

The flow rate of mix from the aspirator was approximatelly 1.36kg per minute. The normal working amount was 7.3 to 10kg of mix. The system, when used in normal production, can hold up to 45.36kg of mix. The more mix used, the longer it remained near the desired mix ratio.

e. Substrate mounting and plating.

The substrate was placed in the substrate carrier and the gun was moved vertically to the top of the substrate. The carrier was then positioned so that the spraying would start at one carner of the substrate. The spray cabinet was closed and the separator turned on. In rapid sequence the vibrator, substrate carrier and air to the spray gun were turned on. The operator then waited until the spray gun had completed one pass. The substrate carrier would automatically reverse direction. During the one second required to reverse, the operator moved the gun down 0.952 ± 0.32cm. After about 8 passes the sample was completed. Each was put in a plastic bag numbered and sealed. A description of specimens by identification number is presented in Table I.

TABLE I

Code Sheet for Aluminum Plated Substrates

Numbers are on the back, top left of the substrate. On Magnesium, the I.D. number is on the front, top left of substrate.

Steel Alloy

1.4-2.1 kg/cm^2

1 Bead cleaned
2 Wire brushed
3 Chemically cleaned
4 Solvent wiped

3.5-4.2 kg/cm^2

5 Bead cleaned
6 Wire brushed
7 Chemically cleaned
8 Solvent wiped

Copper Alloy

Powder to bead ratio in percent

10%

9 Bead cleaned
10 Wire brushed
11 Chemically cleaned
12 Solvent wiped

30%

13 Bead cleaned
14 Wire brushed
15 Chemically cleaned
16 Solvent wiped

50%

17 Bead cleaned
18 Wire brushed
19 Chemically cleaned
20 Solvent wiped

Magnesium Alloy

0.001 inch thick plating

21 Bead cleaned
22 Wire brushed
23 Chemically cleaned
24 Solvent wiped

0.005 inch thick plating

25 Bead cleaned
26 Wire brushed
27 Chemically cleaned
28 Solvent wiped

TABLE I (cont.)

Code Sheet for Copper Plated Substrates

Aluminum Alloy

fine glass bead and -325 mesh copper powder
- 29 Bead cleaned
- 30 Wire brushed
- 31 Chemically cleaned

coarse glass bead and -325 mesh copper powder
- 32 Bead cleaned
- 33 Wire brushed
- 34 Chemically cleaned

fine glass bead and +100 mesh copper powder
- 35 Bead cleaned
- 36 Wire brushed
- 37 Chemically cleaned

coarse glass bead and +100 mesh copper powder
- 38 Bead cleaned
- 39 Wire brushed
- 40 Chemically cleaned

Magnesium Alloy

0.001 inch thick plating
- 41 Bead cleaned
- 42 Wire brushed
- 43 Chemically cleaned
- 44 Solvent wiped

0.005 inch thick plating
- 45 Bead cleaned
- 46 Wire brushed
- 47 Chemically cleaned
- 48 Solvent wiped

Steel Alloy

1.4-2.1 kg/cm^2
- 50 Bead cleaned
- 51 Wire brushed
- 52 Chemically cleaned
- 53 Solvent wiped

3.5-4.2 kg/cm^2
- 54 Bead cleaned
- 55 Wire brushed
- 56 Chemically cleaned
- 57 Solvent wiped

TABLE I (cont.)

Code Sheet for Nickel Plated Substrates

Aluminum Alloy

fine glass bead and -325 mesh nickel powder
- 58 Bead cleaned
- 59 Wire brushed
- 60 Chemically cleaned

coarse glass bead and -325 mesh nickel powder
- 61 Bead cleaned
- 62 Wire brushed
- 63 Chemically cleaned

fine glass bead and +100 mesh nickel powder
- 64 Bead cleaned
- 65 Wire brushed
- 66 Chemically cleaned

coarse glass bead and +100 mesh nickel powder
- 67 Bead cleaned
- 68 Wire brushed
- 69 Chemically cleaned

Magnesium Alloy

0.001 inch thick plating
- 70 Bead cleaned
- 71 Wire brushed
- 72 Chemically cleaned
- 73 Solvent wiped

0.005 inch thick plating
- 74 Bead cleaned
- 75 Wire brushed
- 76 Chemically cleaned
- 77 Solvent wiped

Steel Alloy

1.4-2.1 kg/cm^2
- 78 Bead cleaned
- 79 Wire brushed
- 80 Chemically cleaned
- 81 Solvent wiped

3.5-4.2 kg/cm^2
- 82 Bead cleaned
- 83 Wire brushed
- 84 Chemically cleaned
- 85 Solvent wiped

Copper Alloy

Powder to bead ratio in percent

10%
- 86 Bead cleaned
- 87 Wire brushed
- 88 Chemically cleaned
- 89 Solvent cleaned

30%
- 90 Bead cleaned
- 91 Wire brushed
- 92 Chemically cleaned
- 93 Solvent cleaned

50%
- 94 Bead cleaned
- 95 Wire brushed
- 96 Chemically cleaned
- 97 Solvent cleaned

IV. RESULTS AND DISCUSSION

a. Plating with copper or nickel powder.

An attempt was made to plate the substrates with copper or nickel powders. Neither the size A bead nor the highest available air pressure would cause the metal powders to plate on any substrate. Small holes were drilled halfway thru a substrate in an attempt to force the powder to plate to itself if not the substrate. No significant plating occurred. Both the -100 and -325 mesh sizes of copper or nickel powder was used.

b. Aluminum plating of brass

The aluminum powder was sprayed with no difficulty on the brass substrates purchased for this investigation. In one of the early trial runs, however, a piece of brass did not peen plate well. Studies showed that the only apparent difference between this sample and that which was purchased was that it was unannealed.

c. Plating steel and magnesium

The steel and magnesium plates peen plated very easily. However, the thin magnesium substrate material badly warped due to the bead impact. This problem was partially solved by epoxying the magnesium strips to a heavier piece of aluminum plate. On two occasions however, the stresses set up by peening caused the magnesium strip to peel away from its backing. The thicker steel plate substrates did show some slight bowing. This bowing was on the order of 0.25cm per 15cm length of substrate.

d. Plating non-prepared surfaces

The aluminum coating did not seem to be affected by the surface cleanliness of the substrate. This held true even for those that were in the "as delivered" surface condition. It appears then, that the beads will remove any light surface scale, and the metal powder will remove small amounts of surface oil (such as one would find after handling substrates without gloves). This, although convenient, may pose as a contamination problem in a recycling type system.

e. Effect of mix ratio on plating quality

In the high mix ratio, greater than 40% powder, some evidence of poor adhesion was observed. This is possibly due to the entrapment of fine (+400 mesh) powder. This fine powder, when damp or electrically charged, becomes cohesive and clings to the substrate before any plating occurs. On subsequent peen plating the aluminum is impacted on top of this fine powder, preventing sound bonding. This problem becomes more pronounced as the bead to powder ratio exceeds 40% powder. Examples of this problem clearly showed up on sample numbers 17 thru 20.

On the other extreme, 20% or less powder did not plate evenly. Any slight change in mix ratio will result in a bare area.

The mix ratio that appears to be the best is between 25-35% powder. This value seemed to be independent of the air pressure used. With this mix ratio, the coatings did not flake off nor was the process sensitive to minor variations of the mix ratio as delivered to the gun.

f. Effect of air pressure on plating quality

The velocity, and therefore impact energy, of the sprayed particles is dependent on the air pressure, distance to substrate and spray gun design. A better measure of the actual impact energy is the peening intensity as measured on the Almen gauge.

The air pressure available could be controlled to produce from little peening intensity to better than 0.01A on the Almen gauge. At peening intensities of 0.0059A or less, the vacuum produced in the spray gun was not enough to operate the aspirator, nor enough to deposit the aluminum. Peening intensities of greater than 0.01A tended to abrade material that was peened on, hence, the coating was uneven. The peening intensity that gave the best results was approximately 0.007A. At this intensity the coating deposited relatively rapidly and was not removed by the beads impacted subsequently.

g. Metal powder and bead separation

One of the difficulties with the cyclone separator was that it held the fine metal powder in suspension, resulting in a lower metal powder to bead mix ratio. To help elimina this problem the cleaning port on the side of the mix stora tank was removed and a long sleeved rubber glove was inserte and sealed in. This allowed the operator to reach in and redistribute the powder and beads while the separator was in operation. Although this did not fully eliminate the problem, it did keep the mixture fairly even. Half of a substrate could be sprayed before the system had to be shut down to fully remix the beads and powder.

This problem could perhaps be fully eliminated by using a recycling system that did not use a cyclone separator. Rather than vacuum the spray cabinet, the spent mix would fall directly into a storage tank. This would require that some form of venting be included to allow escape of the spray gun's air.

h. Dry nitrogen propellant.

There was difficulty with water in the air supply. As mentioned under e. of this section, this water may have caused the powder to adhere to the substrate surface. Occasionally small sprays of water would come from the spray gun. Dry nitrogen gas was initially used to correct this problem. Although no water spray was evident, the metal powders still adhered to the substrates surface. This remedy also proved to be very costly, as 8490 liters of gas is used in a matter of minutes. No further work was done with dry nitrogen gas.

i. The plating of alumina.

A very short time was spent using ceramic substrates. It was thought that the nickel or copper powder might deposit on a harder surface. These powders did not plate. However, the aluminum powder did plate well on an alumina substrate.

j. Some factors involved in the plating process.

As the hardness of the substrate surface did not appear to improve the nickel or copper plating, alternate explanations were considered. One is the relative modulus of the bead and that of the metal powder. Aluminum has the lowest modulus of the metals used-and nearest to the modulus of glass.

Another factor is the malleability of the metal. Pure aluminum is very soft and malleable. This makes it easy for the impact bead to smear the metal onto a surface. Copper and nickel do not possess such characteristics.

A third consideration is that of powder size. Both nickel and copper powders had a major fraction in the vicinity of 200 mesh. The aluminum powder had the major fraction less than 325 mesh. To test the aluminum on a more even basis with nickel and copper, it was screened and only the +200 mesh powder used. The small "H" bead did not plate this powder, but the size A bead did.

There consequently appears to be relationship between the bead and metal partical mass. The figures in Table 2 give some indication that this is true, but only for a particular metal. The size A bead will peen any particle of aluminum to a surface if the particle size is 200 mesh or smaller, while neither bead size D or H will. Size D bead will plate 325 mesh or smaller powder and size H will only plate aluminum powder of even smaller dimensions. This can be seen graphically in Figure 5. This type of graph could be made for any of the metals assuming that mass is the only, or at least the major, factor involved in peen plating.

k. Conclusion

The process is extremely practical in plating aluminum. The aluminum can be deposited on metals at a high rate, much faster than competitive processes. The process does not involve any flammable or toxic liquids or gasses, and the equipment required is relatively inexpensive compared to other aluminum depositing processes. The mechanical and electrical properties of the deposited aluminum need, however, to be evaluated.

Other soft metals require further investigation. Harder metal could possibly be plated by using larger glass impact beads, steel shot or some other denser and harder peening material.

In conclusion, the peen plating process for aluminum has been demonstrated and with further development will easily become economically superior to other plating processes.

Table 2. Volume and mass of powders used

Note. The volume and mass are based on a spherical shape.

Glass Bead U.S. Sieve Size		Radius mm	Volume mm^3	Mass gram
A	20	0.420	3.103×10^{-1}	7.757×10^{-4}
	30	0.297	1.097×10^{-1}	2.742×10^{-4}
D	50	0.148	1.358×10^{-2}	3.395×10^{-5}
	70	0.105	4.849×10^{-3}	1.212×10^{-5}
H	100	0.074	1.697×10^{-3}	4.242×10^{-6}
	140	0.052	5.890×10^{-4}	1.472×10^{-6}

U.S. Sieve Size	Radius mm	Volume mm^3
100	0.074	1.697×10^{-3}
150	0.053	6.236×10^{-4}
200	0.037	2.122×10^{-4}
325	0.022	4.460×10^{-5}

U.S. Sieve Size	Mass of a Metal Particle (grams)		
	Al	Ni	Cu
100	4.583×10^{-6}	1.511×10^{-5}	1.514×10^{-5}
150	1.684×10^{-6}	5.550×10^{-6}	5.563×10^{-6}
200	5.729×10^{-7}	1.888×10^{-6}	1.893×10^{-6}
325	1.204×10^{-7}	3.969×10^{-7}	3.978×10^{-7}

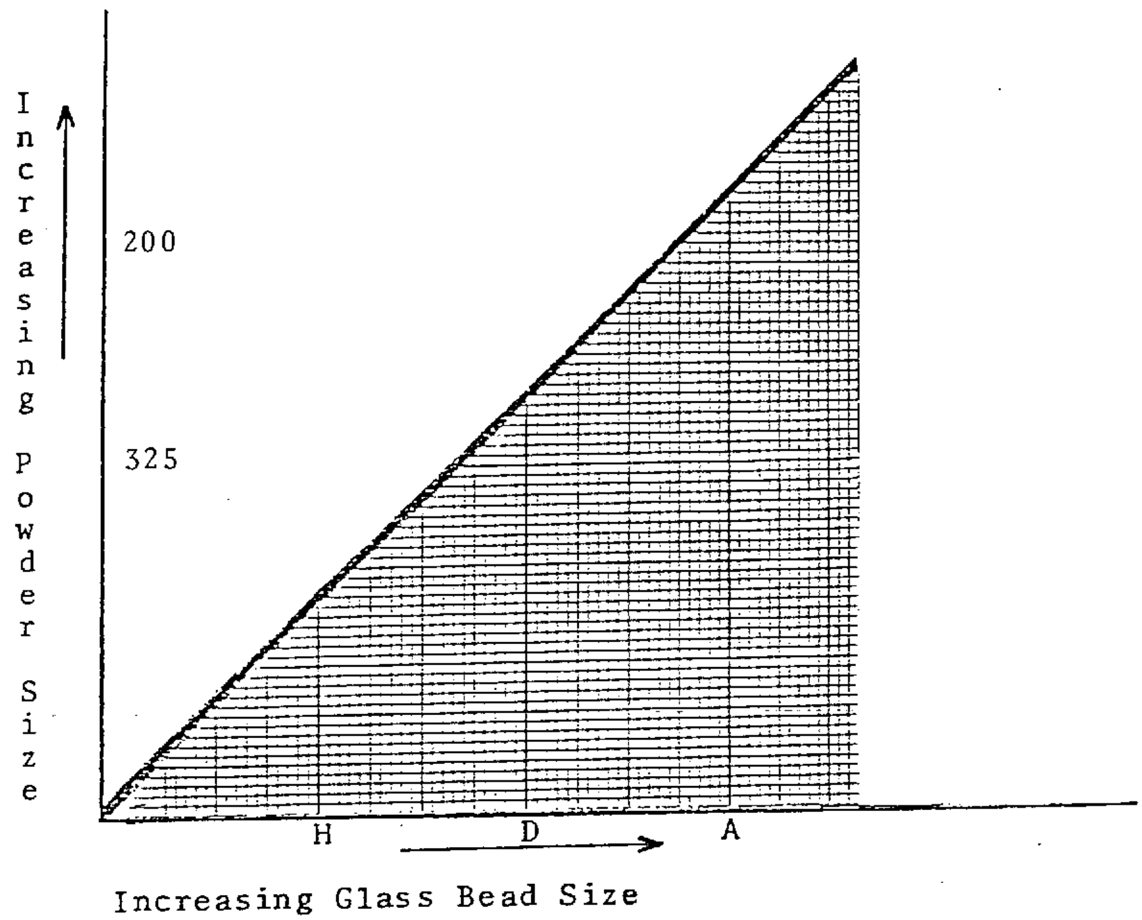

Figure 5. Size of bead required to peen on a given aluminum powder size. The shaded area represents the aluminum powder sizes that a given bead size will plate.

Note: The slope of the line is estimated.