HOW, WHEN AND BY WHOM WAS MECHANICAL PRESTRESSING DISCOVERED

by G. F. Bush, in collaboration with J. O. Almen,
L. A. Danse and J. P. Heiss

Prestressing of metals by mechanical working to obtain improved strength and fatigue characteristics has been developed gradually over many years.

In pressing the investigation of the history of mechanical prestressing, a most revealing description of the apprentice system was found which explains the lack of specific knowledge on any of the early trades or arts.(1) The apprentice was bound over to his master by a legal document called an indenture. It was registered and kept on file in the city office by a court officer. The period specified varied from three to twelve years depending on the trade, but was usually for seven years. During this time the apprentice lived with or on the premises of the master and was fed, clothed, housed, and sometimes schooled as specified. He served his master faithfully and lived a straightforward life including keeping his master's secrets. In exchange, he would learn all the skills from the master so that he would be knowledgeable when he came into his own. Also, the master was duty bound not to convey his secrets to others and thus dilute the exclusiveness of the trade. This worked both ways and accounts for the lack of specific information on how things were done as they were mutually bound by this pact to secrecy. Accordingly, it is not possible in every instance to give names and dates with no fear of contradiction.

Hammering is undoubtedly the oldest form of mechanical prestressing in the sense of stressing a metal beyond its yield strength. An exquisite gold helmet found at Ur dates back to 2700 B.C. The lost art of hardening copper as done by the Phoenicians is thought to be that of cold hammering. Certainly it was known at the time of the Crusades (1100-1400 A.D.) when knight's armour was cold worked to final shape and hardness. No doubt it was known to the blade makers of Damascus and Toledo as their blades were not only hard, but were celebrated for being flexible. However, these applications did not utilize the process to induce residual compressive stresses to combat fatigue, but rather to shape and surface harden. Nevertheless, hammering has been used for many years to improve fatigue life. Mr. A. C. Sampietro reports that the fillets of crankshafts for European race cars were hand peened with specially shaped small hammers, as early as 1922.

Rolling, which has substantially displaced hammering in the production of prime materials, is one of the most important methods of mechanical prestressing. Strangely, there is no record of cold rolling being invented. Apparently, it occurred simultaneously with hot rolling as inherited practices from hammering, where both were employed. The first record of rolling occurred in France in 1553 for insuring metal of uniform thickness and density for coinage.(2) Then Christopher Polhem, in the early 1700 period in Sweden, rolled iron at ten to twenty times the rate it could be "tilted" under a hammer.(2) He died in 1751. In England, Henry Court took out patents on grooved rolls in 1783. (2) In this country, Lauth's patent for three high plate and sheet rolls was taken out in 1872 – which used a small diameter roller backed up by a rigid larger roller, to cold work steel into thin sheets or shapes.(2) Strangely, Christopher Polhem employed the same principle, only four high, two

(1) Kauffman "The Gunsmith" p. 8
(2) Harbord-Metallurgy Steel, p. 316

centuries before and must have done it for cold rolling purposes too, but it was not reported as such.(3) The effectiveness of Lauth's process on cold rolled shafting over hot rolled shafting, or shafting turned to the same diameter, is reported jointly in 1872-74 period both here and abroad by Prof. Robert Henry Thurston of Stevens Institute of Technology (later of Cornell and first president of ASME), Major William Wade U.S.A. and Sir William Fairbairn F.R.S. (bridge building, inventor of riveted boiler, and sectionally built steel ships) from samples supplied by Jones and Laughlin of Pittsburgh.(4) The gain in bending was 2 to 3-1/2 times, in torsion 2-1/3 times, in compression 1-1/2 to 2.6 times, in tensions 1-1/2 to 2 times. Surface hardness by indentation method was 1-1/2 times the weight to give the same diameter of impression. The Philadelphia firm of William Sellers and Company, who were heavy ordnance and machinery suppliers at this same period, quote strengths of wrought iron shafts from 1" to 20" in diameter and then give factors for working stress of steel of 2.06 times, which corresponds with previous data.

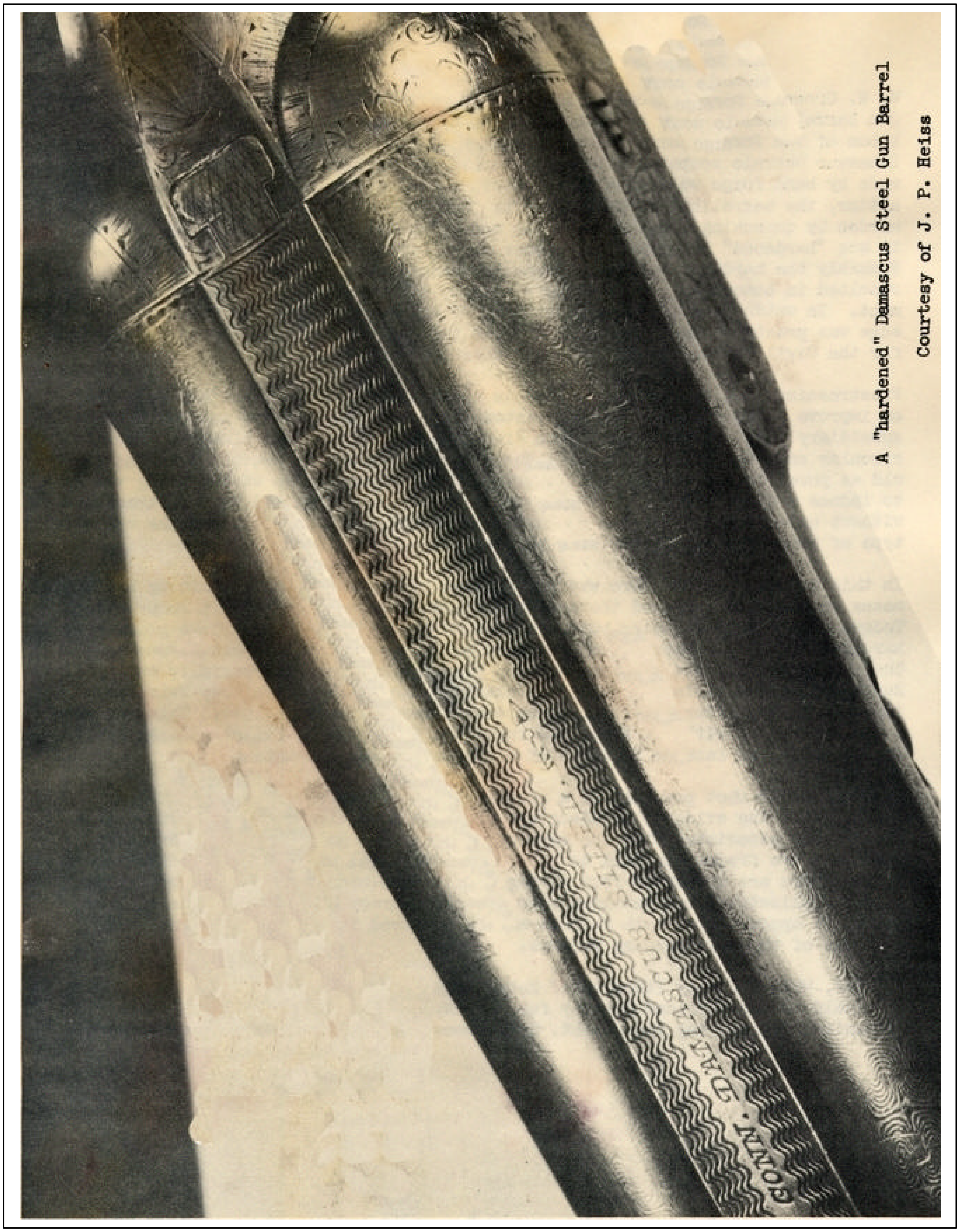
Another report on this period is that of Guy Hubbard, Machine Tool Editor for the magazine STEEL, reported in an editorial dated January 8, 1951, "I recall conversation with the late Christopher Miner Spencer, who invented the original 'automatic' (screw machine) 80 years ago. Not only did he apply roll burnishing to his early automatics, but he in turn recalled having seen this method applied to finishing of journals on railroad axles when he first became a journeyman machinist way back at the time of the Mexican War."

Mr. Almen writes, "I have been reliably informed that a booklet supplied to apprentices by the Canadian Northern Railway (now Canadian National Railway) in the 1880's described the rolling of shafts as a process of obtaining a smooth finish and for strengthening."

A survey of the literature indicates that the early proponents of surface rolling valued the process for smoothing and strengthening shafts. Even investigators such as Poppl ascribed the benefits of improved strength, following the process, to increased hardness. Thum and Bautz(5) appear to be the first to content that the benefits were due to residual stress.

The arts of gunmaking and of watchmaking both testify to the early knowledge of the importance of dense surface structures.(6) In a detailed account of gun barrel welding by Acton of London in 1789, "A circumstance of considerable importance to the excellence of a barrel, is, the forging it as near as can be to weight it is intended to be when finished, so as little will be taken away in the boring and filing, for as the outer surface by having undergone the action of the hammer more immediately than any other part is rendered more compact and pure, we should be careful to remove as little of it as possible." Similarly

(3) Harbord-Metallurgy Steel p. 348
(4) Joshua Rose "Machine Shop Practice" p. 188
(5) Thum, A., and Bautz, W.: Steigerung der Dauerhaltbarkeit Gekerbter Konstrucktionsteil durch Eigenspannungen. Vereine Deutscher Ingenieure, Zeitschrist, V.78, no. 31, August 4, 1934, p. 921-925
(6) H. J. Kauffman "The Gunsmith" p. 26



A “hardened” Damascus Steel Gun Barrel
Courtesy of J. P. Heiss

W. W. Greener of Birmingham in his book Gunnery in 1858 discusses the merits of gun barrel steel by way of introducing cold hammered nail stubs into the fused bloom of the forged barrel blank. Later he discussed the merits of “hard” Damascus barrels compared with soft ones. Knowing that the hard barrels were made by hand forge welding a spiral strip around a mandrel, still in place. Probably the hardness was not materially changed, but rather the hammering resulted in beneficial compressive stresses, which produced the desirable improvement. In watch- and lockmaking, rolling of mainsprings both for thickness and edge was practiced quite early to improve fatigue resistance. Clocks and watches for the Civil War period show clearly this knowledgeable practice.

Prestressing locally has many facets in which the objective is either to shape, or improve fatigue life. Peening piston rings was an early art and the Koppers' subsidiary American Hammered Piston Ring Company, implies its history. Peening circular saws for truing and for reducing stress at hub to prevent cracking is as old as power sawing of lumber. Sleeving of large guns, also wire winding was done to induce a compressive stress at surface of bore and thus add to the stress range without exceeding the tensile strength when fired. Autofrettage was the opposite type of prestressing for the same purpose.

In this process the gun bore was prestressed beyond the elastic limit by hydraulic means so that when relaxed the bore would have residual stresses in compression. Today, small arms are being button rifled or hammer rifled to achieve great bore hardness, residual compressive stresses, and improved straightness. Recently, the rolling of fillets for prestressing purposes has been successfully employed. Buick rolled the fillets of the crankshaft of the Pratt and Whitney Twin Wasp improved engine after experiencing an engine test failure in 1944. This was done in collaboration with Mr. Almen who furnished the original fillet rolling tool. Subsequently, no fatigue failures of crankshafts were encountered.

Turning now to shot peening, as a relatively recent development it might be thought that the evidence of discovery might be more clear-cut. However, while the secrecy associated with the apprentice system is no longer a factor, shop practices are frequently held to be of a confidential nature and the discoverers or inventors are prevented from making public disclosures. In addition, where patent applications are involved even greater secrecy may prevail. As will be shown, it appears that both factors may be involved in naming the actual discoverers of the shot peening process.

In 1946, Walter Jominy (the Chief Metallurgist for Chrysler Corporation) acting on behalf of the American Society for Metals, asked J. O. Almen (the Head – Mechanical Engineering Department, G.M. Research Laboratories) to prepare background information for an award [7] to the late F. P. Zimmerli (the Chief Engineer, Barnes-Gibson-Raymond Division). In the course of his investigation, Mr. Almen surveyed the literature and reported as follows.

The earliest published material on shot peening is by E. G. Herbert. In March, 1927, he wrote on the "Work-Hardening of Steel by Abrasion" with an Appendix on " 'Cloudburst' Test and Superhardening".[8] Herbert, however, was primarily concerned with the increase in hardness, rather than in increasing fatigue durability.

In April 1929, Mr. O. Poppl published an article in Stahl and Eisen. On page 576, five fatigue specimens are shown which were penned with a hammer having a 4 mm ball end. Of the five shown, four broke in the non-peened section under fatigue loading, notwithstanding the reduced section where the peening had been applied. This is the first known publication in which fatigue durability is shown to improve with peening.

The Transactions of the ASME, December 1935, contain a paper by E. E. Weibel on "The Correlation of Spring Wire Bending and Torsion Fatigue Tests". In it he describes the use of shot peening to prevent fatigue failures in torsional fatigue tests and included pictures of the specimens as well as data. Weibel makes reference to the work of Poppl and in his acknowledgements, refers to F. P. Zimmerli.

J. H. Frye and G. L. Kehl presented a paper before the AWS in Atlantic City in October 1937 entitled "The Fatigue Resistance of Steel as Affected by Some Cleaning Methods". This was published in the Transactions of the ASM in March 1938. It describes the increased fatigue durability obtained from specimens which had been variously treated by sand blasting and shot blasting. The authors refer to the earlier work by Weibel. There is an interesting comment in the discussion on page 213. W. E. Harvey of John A. Roebling's Sons Company states "The question of sand blasting versus fatigue studies while not new deserved richly the attentions the authors have rendered it." We do not know the source of Mr. Harvey's earlier acquaintance with the process and the benefits to be obtained.

F. P. Zimmerli published a paper on "Shot Blasting and Its Effect on Fatigue Life" in April 1940. This was his earliest paper on the subject of shot peening and refers to the work of Herbert only. However, in the discussion, Mr. T. G. Harvey makes reference to the work of Frye and Kehl. Zimmerli said in his reply that he was in substantial agreement with those authors.

(7) Albert Sauver Achievement Award granted to Mr. Zimmerli in 1947
(8) Iron and Steel Institute Journal, V 116, No. 2, 1927, pages 265-291
Also, American Society for Steel Treatment Transactions, V 16, No. 1, July 1929, pages 77-92

"It is rather surprising", said Mr. Almen, "that an earlier paper by Zimmerli, 'Permissible Stress Range for Small Helical Springs', University of Michigan Bulletin, July 1934, makes no mention of shot peening. There is reason to believe that he had observed improved fatigue durability of shot blasted springs prior to this publication. On page 14 he mentions the improved strength which would result from pressing the springs solid – a process which like shot peening had been practiced as an art for a very long time."

In a letter dated March 21, 1962, Mr. Almen stated that he had not intended to comment further on the probable cause of the delay by Zimmerli in publishing his shot peening experience. However, Almen said that some of his own experience in attempting to prepare a paper on shot peening for Detroit Chapter ASM in 1936 or 1937, leads him to believe that Mr. Zimmerli was seeking a patent.

Turning now from published evidence, Mr. Almen reports a conversation with Mr. M. T. Mortensen, Manager, Detroit office of American Foundry Equipment Company (now Wheelabrator Corporation) in the early 1940's. Mr. Mortenson said that a Detroit manufacturer had a product which failed a specified test for strength during World War I. After shot blasting the same parts did not fail. Unfortunately, Mr. Mortenson was unable to remember the name of the manufacturer and his story cannot be substantiated. John C. Straub, Chief Research Engineer, American Wheelabrator Corporation, reports "I recall him (Mortensen) quite clearly, because of association on a number of peening jobs, but I do not recall any reference to World War I in this connection. Mr. Mortensen has been dead for a number of years, but I have talked with Mr. R. O. Orth, Manager of the West Central Region of Wheelabrator Corporation. Mr. Orth was with Mr. Mortensen during the early 1940's, but he does not recall any reference to the elimination of failures by shot peening during World War I."

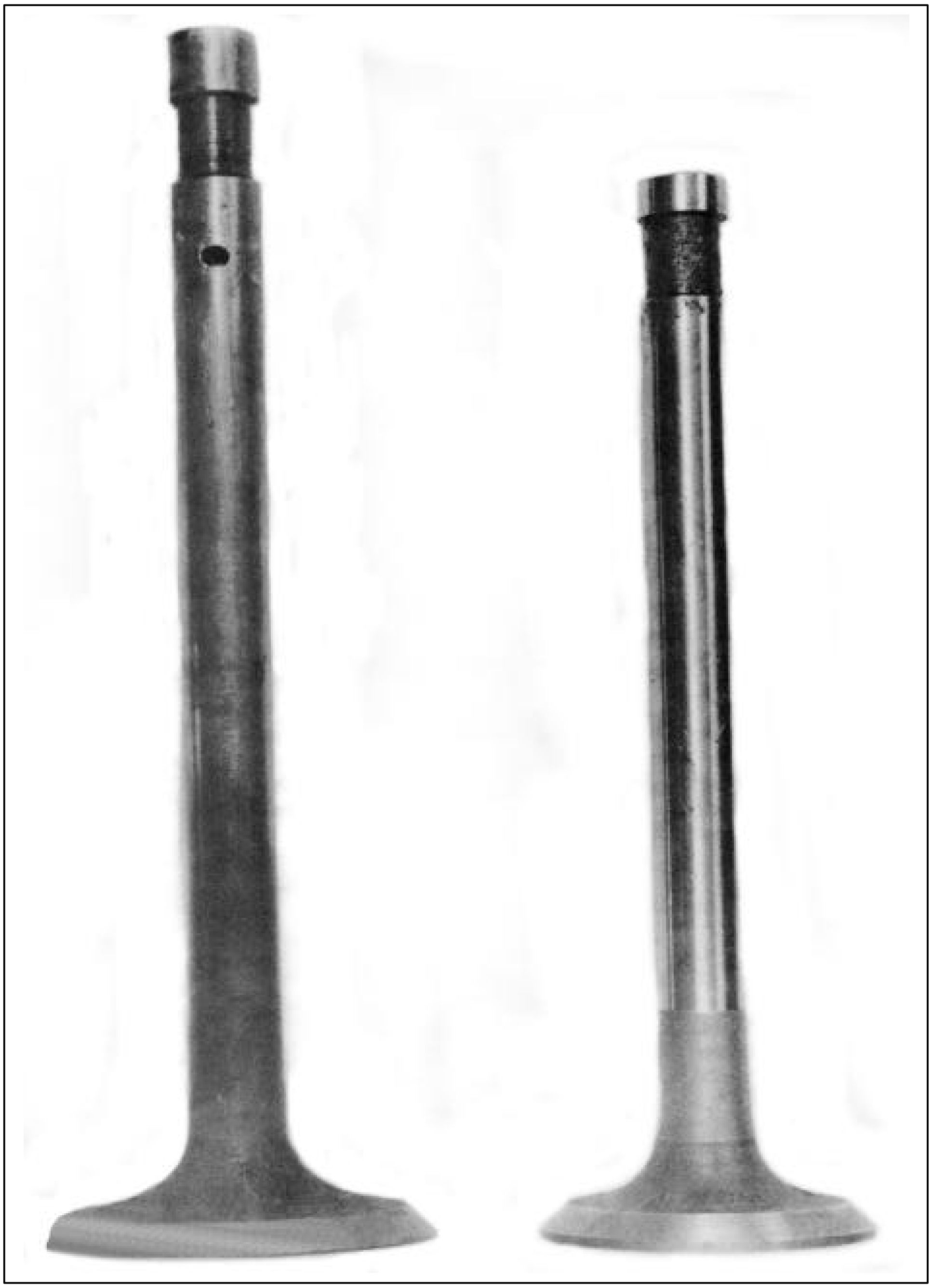
Much more positive evidence exists that shot blasting of springs was done to improve fatigue durability at Cadillac Motor Division, G.M.C., in 1926-1928. Mr. H. G. Taracks, Assistant Metallurgist, and Mr. L. A. Danse, Chief Metallurgist, performed the work and Mr. Danse has reported as follows:

"In 1923 four wheel brakes were introduced on a new car placed on the market by E. V. Rickenbacker, World War I Ace.(9)

The increased effectiveness of four wheel brakes forced the whole automotive industry to follow suit.

Prior to four wheel brakes, few drivers operated cars over 55-60 mph, as the two wheel brakes would not control the high speed stopping potential. Four wheel brakes controlled stopping so much better that speeds quickly went up to 70 mph or higher.(10)

(9) It is believed that the Duesenberg was the first American built car, other than race cars, to have four wheel brakes in 1920.
(10) Paved roads extending as far as 3 miles from city limits and "seedling" miles built in strategic locations by the Portland Cement Association, as well as the general adoption of cord tires probably contributing factors in increased speeds also.



These valves are identical for lift, guiding and porting height. The difference in length is due to the elimination of the cottered safety hole, made possible by the more reliable shot peened valve springs. The cotter pin kept the valve from falling into the valve-in-head engine after spring failure.

Faster habitual driving, together with the increased stresses of high speed stops, caused weaknesses in car design and construction to hamper performance (previously unnoticed at the old, lower speeds).

This initiated an intensive campaign to improve life of various car parts – stem to stern. Things which had formerly served at the slower two wheel brake speeds were inadequate at the higher four wheel brake speeds and gave trouble in service as drivers souped up top speeds.

The first part to demand attention was the valve spring. At the higher speeds afforded by four wheel brakes, valve spring life was utterly inadequate.

In the early Twenties, spring wire of SAE 1095, CAD 4155, MRD, and other types then current, had served satisfactorily. By the mid-Twenties material was changed to SAE 6150. As the campaign progressed, 6150 was exploited to the limit. Although spring wire was purchased from Halcomb Steel Company in a special grade, it was not good enough.

Therefore, Cadillac Laboratory originated the requirements for “clean steel” and developed sampling methods and microexamination tests to rate cleanliness. With this class of steel, to tight sonim requirements, some improvement was achieved and this “clean steel” requirement spread rapidly throughout steelmaking and procurement circles. But the valve springs, with all these premium extras, were still not good enough.

It became customary to run high speed fatigue tests on samples of springs from each shipment received from spring fabricators. These samples were selected by metallurgists who first deep-etched some to check for surface defects and then sent a bundle of springs to the engineering department where they were run in the dynamometer laboratory in high speed engines before being released to production.

This running testing enabled further study of spring performance, but was so tedious and costly that a special testing machine was built and installed in the Metallurgy Laboratory in 1927 to speed it up. This machine utilized all the standard engine parts of the valve train from camshaft and bearings to valves, but was so designed as to permit quick dismounting and re-assembly of all the components, particularly springs. The machine was driven by a heavy variable speed electric motor to permit precise speed control and speed variation ‘surging’, throughout which action the springs could be stroboscopically observed.

Installation of this device marked a stride ahead in study of spring action and performance.

One feature early observed in running of this valve spring tester was that the current method of cleaning springs after heat treatment was not satisfactory as it was noted that scale popped off springs when run at speed. At that time, springs were barrel tumbled to clean them.

Pickling was tried, but as little was then known of causes or remedies for what was later decided to be hydrogen embrittlement, it was found that the pickled springs had markedly shorter life than tumbled springs and pickling was quickly discarded.

A batch of springs were then cleaned in one of the barrel shot blast machines used for cleaning small parts in Heat Treat. This trial gave the answer to the scale problem, and when these springs were run in the testing machine, they showed much longer fatigue life, and actually at increased speeds.

Accordingly, routing sheets were changed to call for valve springs to be shot blast cleaned after receipt and before sending to test, prior to production.

Concurrently, with this study, work was being done on connecting rods and conn rod bolts. Modifications in processing (connecting) rods were nearly parallel to development of valve springs.

Steering arms and knuckles were changed from pickling cleaning to shot blast cleaning with remarkable increase in fatigue life.

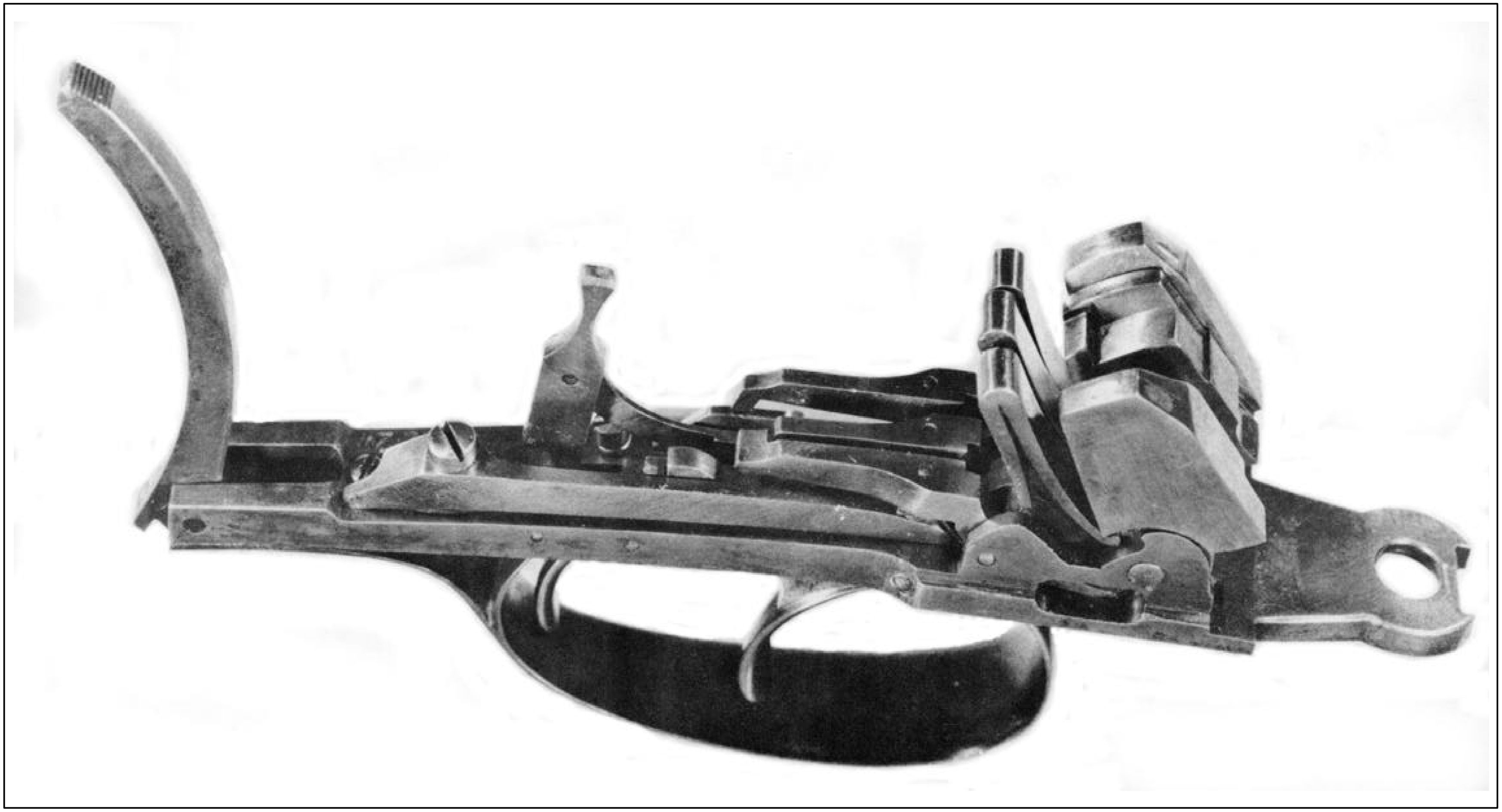
Rear axle shafts were so much improved by changing to shot blast cleaning that the size could be reduced and the steel changed from an expensive high alloy to a cheaper medium alloy, providing a much better shaft at far lower cost.

Ring gears and pinions were made much easier to ‘lap in’ and ‘match’, after shot blasting, besides having better tooth wear and breakage characteristics. It was to be years later before the mechanism of the metallurgical benefit would be figured out. But intensive study, even by the then available cut and try methods demonstrated the improvement from shot blasting, as it was then called; which, although first tried as a cleaning method to get rid of scale, showed up on the spring testing machine to significantly improve fatigue life.”

Another early investigation of the beneficial results of shot blasting on valve springs took place at the Buick Division of General Motors in 1929. Mr. Otto Burkhardt and Mr. John Paul Heiss were assigned to the problem of correcting or preventing valve spring breakage.

Mr. Heiss kindly recorded the story of their investigation for Mr. Almen on January 28, 1948. His story is as follows:

“Late in 1929 and early 1930 as the activity in zero lash subsided, Mr. Burkhardt was working on valve spring breakage which was not a new problem: it was a perennial problem. We had a dummy engine going in which we placed a set of valve springs and ran them at high speed. Inside of twenty-four hours at least three of the twelve springs would be broken. We observed that if we took springs which had survived these tests and kept running them, they would continue to run for a long, long time. But in almost any random choice of new springs, we would get a substantial quantity of breakage early in the test. This observation channeled



Polished springs in an old gun trigger mechanism. Polishing was used to minimize or eliminate stress risers and so improve fatigue characteristics.

Courtesy of J. P. Heiss

our thinking that the design was satisfactory but that the trouble lay in individual springs. Accordingly, we looked for internal and external flaws in the wire, both in springs broken and by trying to select springs with apparent flaws where we could expect breakage. Our efforts were not conclusive because the break did not occur in the worst flaw in a given spring, and those we selected as bad would not always break. When we discussed flaws and notching effect with Cook Spring Company's (our commercial supplier) representative, Bill Schole, he would snort, 'You are asking for something that is not commercial', and, 'To avoid surface imperfections we would have to grind the stock before coiling'.

"Inasmuch as we weren't getting anywhere with the supplier and our tests, Mr. Burkhardt came up with another idea: it must be kinks in the wire. Our outer valve spring at that time, and yet today, has a changing pitch which gives basket coils and working coils; and the only way I knew how to determine 'kinks' was to mount the springs on a dividing head with an indicator to take numerous equal angular spaced lead measurements with an indicator bearing on the coils. I must have worked at least two months on this problem and wasn't satisfied with the results. Obviously, the data could not be judged as it was taken, due to the variable lead of the spring; it had to be plotted to show abrupt changes in lead. Often the change in lead point was just a bump; and when this same spring was rechecked it did not show at all unless the same angular displacement as originally employed was repeated. Upon close examination, some of these bums, I thought, were attached flakes of scale and it occurred to me that if the spring were shot blasted to get them clean, my job would be easier and I could better concentrate on the problem.

"Accordingly, the next time the Cook Spring Company representative called, I asked that at least four springs in the next batch of samples be prepared with shot blasted wire. When this batch of springs came, someone had misunderstood and all were shot blasted. Mr. Burkhardt was upset and blamed me for the mistake, but later concluded that he would run them anyway because the test machine was down; and to keep our work alive in the laboratory, it was desirable to do anything, right or wrong.

"Much to our surprise, none of these shot blasted springs broke on the dummy engine test. Mr. Burkhardt was quite excited and called up the Cook Spring Company of Ann Arbor. He told them about the successful test and asked them what they had done to the springs to improve them. Of course, they had the inside track. They knew exactly how these springs differed from previous test batches; and we didn't. Furthermore, Mr. Burkhardt did not inform me at any time the results of his conversations with them as I kept on checking springs for awhile. But the dummy engine tests showed that the problem was solved, and I was given other work.

"Answering your (Almen's) questions directly: (1) I believe that the origin of the shot blasted spring to increase fatigue life stemmed from this work at Buick. (2) Otto Burkhardt was in charge of tests on valve gear. (3) Both he and I observed the results of the improvement on this batch of shot blasted springs before anyone else knew about it. (4) Since I was an assistant, and did not have the contact with the supplier, I don't know who first associates the improvement

FORM B-407 5M 4-30 PERRY

BUICK MOTOR COMPANY, FLINT, MICHIGAN

BM-154

MANUFACTURING ENGINEERING CHANGE REQUEST

DELIVER THIS COPY TO THE PRODUCTIVE COST DEPARTMENT

PART NO. 1245836

PART NAME Spring - Valve - Inner DATE 12-3-30

REQUESTED BY C. A. Chayne FACTORY NO. 78, engineering dept. REQUEST NO. 18185

APPROVED—FACT. MGR. SUPERSEDED BY SUPERSEDES

SERIES	850 L. H. D.	850 R. H. D.	860 L. H. D.	860 R. H. D.	880 L. H. D.	880 R. H. D.	890 L. H. D.	890 R. H. D.
MODELS	all	all						
NO. REQD.	16	16						

MATERIAL

MARKED PRINT

SHOP USE THIS COLUMN

THIS REQUEST REQUIRES AS FOLLOWS:

DIE CHANGE

PATTERN CHANGE

TOOL CHANGE

MACHINE CHANGE

EQUIPMENT CHANGE

STOCK IN PROCESS: TO BE USED yes; TO BE SCRAPPED; TO BE REWORKED

CHECKED

APPROVED

K. D. SPEC.

PROD. SPEC.

EXPER. SPEC.

PURCHASE LIST

CARD RECORD

SERVICE STOCK EFFECTED no

INVESTIGATED AND APPROVED

BY MANUFACTURING DEPT.

BY C. A. Chayne DIVISION ENGINEER—ENG. DEPT.

BY A R Sterling 12/16 SPEC. ENGINEER—ENG. DEPT.

BY PRODUCTION ENGINEER—ENG. DEPT.

APPROVAL COMMITTEE

PRODUCTION DEPT.

EFFICIENCY DEPT.

PURCHASE DEPT.

MASTER MECHANIC

SERVICE DEPT.

MANUFACTURING DEPT.

COST APPROVED DATE 12/18/30

THIS CHANGE IS EFFECTIVE DATE 12-22-30

DETAIL NATURE OF WORK

Note added: Shot blast with steel shot of .080 or less diameter.

Camel Note: Wire brush springs all over to remove all abrasive.

Camel note removed
Shot blast note added

REASON FOR CHANGE

To clean springs thoroughly - manufacturer's request.

REMARKS AND STOCK SIZE CHANGES

This note also to be added to the following:

- 181786 - Spring - Valve - Inner 8-60, 8-80 & 8-90 Series
- 1239847 - Spring - Valve - Outer 8-50 Series.
- 1246449 - Spring - Valve - Outer 8-60, 8-80 & 8-90 Series.
- 1245835 - Spring - Valve Lifter 8-50 Series.
- 207879 - Spring - Valve Lifter 8-60, 8-80 & 8-90 Series.

No change in part.

THIS SPACE TO BE USED FOR COST

due to shot blasting. Furthermore, I don't know if Mr. Burkhardt knew because many things were being tried and in his own mind he may have believed that the improvement was due to other factors. Personally, I thought shot blasting helped because it was the turning point in a hard-to-solve problem. (5) Subsequent springs were shot blasted to expose or clean off imperfections and this was later adopted on production springs as a precautionary inspection expedient.

"Checking up on the drawings, I find that the first drawing showing shot blasting was #181786, after change letter 'D', dated 12-22-30. The Change Request #18185, dated 12-3-30, shows ironically that the change was made to facilitate cleaning and was at the manufacturer's request. It makes no claim for increasing fatigue life. It was requested by Mr. Chanye, then the newly appointed head of the Engine Department, as a routine matter. It was signed by Messrs. Bower, Hertrich, and Chayne and initialed by others." (Charles A. Chayne is now a Vice President of General Motors Corporation.)

In a letter dated February 5, 1962, Mr. Heiss commented: "Maybe I have conveyed the impression that the benefits of shot blasting were accidentally discovered. Quite the contrary, I knew as early as 1920 the polishing springs in fine guns was a prerequisite to good life; also, that airplane and racing engine rods and cranks were polished to avoid the notching effect of surface imperfections. Furthermore, we at Buick had previously discussed surface flaws and notching effect with the spring supplier and the need for improvement of surface finish of springs when he countered with the remark that 'Grinding before coiling was not commercial'. Therefore it was apparent to me after knowing of the successful test results that there was a high probability of the shot blasting alone being the reason for improvement because it corrected the surface imperfections by mechanical working."

Mr. Heiss added still more information on April 17, 1962. A letter addressed to him, from Mr. H. H. Clark, General Manager, Eaton Manufacturing Company, Spring Division, and dated April 9, 1962, said in part:

"In accordance with our discussion, I have searched certain records relating to the shot peening of springs but have been unable to find anything which would be definite enough for your purposes. I did come across old notes which were made at the time we were installing shot peening equipment at the Cleveland Wire Spring Company. This equipment included a 12" x 10" Ingersoll ER-1 Air Compressor and two New Haven Model A Blast Barrels. My notes indicate that the installation was made in July 1929, and I know that we had determined several months before the purchase of the equipment that shot peening had a beneficial effect on fatigue life; whereas sand blasting tended to reduce it.

"I also ran across a note dated July 2, 1929 which says: 'Shot seems better than grit as it burnishes more and pits less. Shot should be a little courser than that used on test.'

“I also ran across an operational flow sheet for the manufacturer of Cadillac valve springs dated December 12, 1929 indicating that ‘steel blast’ was at that time an accepted part of our processing. However, as I mentioned to you, I remember having made our first shot peening application on Chevrolet rather than Cadillac valve springs.”

Thus the question of who discovered shot peening cannot be readily answered from completely documented evidence. Certainly Danse and Taracks at Cadillac and Burkhardt and Heiss at Buick were among the early investigators. To Zimmerli goes the credit of introducing shot blasting of valve springs to other manufacturers and indeed to J. O. Almen himself. Almen not only was the inventor of the controls used for the process, but also was probably the first to recognize that the benefits conferred were the result of residual compressive stresses, rather than of superficial surface hardening. He undoubtedly has done more to apply and to publicize the process than any other single person.

The question of when and how the process was discovered are somewhat more clear cut. The data would indicate that it took place between 1927 and 1929 in response to a pressing need by the automotive industry.