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The Unsatisfactory Situation in Residual Stress Evaluation

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1 Abstract

Shot peening and its measuring tool "Almen procedure" are chained together ever since. As the process of shot peening has been improved considerably and numerous variations have been developed in the past 60 years, no real effort can be noted on the measuring side, at least not for industrial application. Other possibilities such as X-ray diffraction, Barkhausen noise principle and others have not been able to meet industrial needs so far. Statistical process control tries to solve the problem from a different point of view. The creation of new residual stress evaluation methods is still a challenge to scientists. All people involved in shot peening, regardless of origin or tradition or commercial affiliation should feel free to raise new ideas. This for the reason to make shot peening more economical, more simple, more reliable and to expand this technology into the field of further industrial applications.

2 Present Situation vs. the Engineer's Dream

Consider todays daily procedure, e.g., in a maintenance and repair peening workshop: The qualified operator gets a work-piece and some papers such as part drawings, job instructions, photos, fill-in forms, time sheets or other documentation. He or she is in charge for a peening machine with media management, some measuring gear and special tools and is supposed to do his or her job under full responsibility.

Happily, the operator will put up a dummy to simulate the work-piece to follow. He or she will put up Almen blocks, will install the strips, will do the mechanical setting and the setting for a first life run. Following that, the operator will go into the commonly known Almen procedure and after repeated test runs, will be satisfied with the results acquired with all the parameters. Then the set-up with the original part and the effective peening process are to follow. After that, rigging down, completion of paperwork and that's it.

As experience of over half a century show, this works quite well and even at acceptable costs. But the component design engineer works, or should work, with residual stress-depth profiles and various surface conditions, at least when he or she is concerned about fatigue. This means true physical figures, that can be evaluated and also measured on the effective work-piece. And these figures must be found again in the workshop, must be recognizable on the work-piece, before or after a treatment. This is the aim that should be taken into consideration over the next few decades. Then and only then, we will have the standard of most other industrial measuring processes, in other words:

1. Step: Actual value measured
2. Step: Process performed
3. Step: Desired value measured (aim of process)

Certainly, the task is not simple, and was not even possible in the past. However, with the fast development in micro and electronic engineering, all involved people should support this

Table 1: Possible evaluation methods for shot peening-induced residual stresses

a	Principle:	Destructive	Non-destructive	Simulated	
b	Technique:	Fatigue testing (and exotic)	Physically scientific	Direct Mechanical	Indirect resource related
c	Procedure:	Lifetime test run	Examination process	Process related intensity and coverage set-up copied over to original partShort interval specific conformity check after time periods (4 hrs . .)	Process control based Machine calibration and transformation to part Longtime interval standard conformity check after time periods (1 shift . .)
d	Tools:	Materials testing machinery	X-Ray/Neutron and Magnetism based instr.[b] "XRD, BNA"	Metal plate with deformation measuring equipment "PDT"	Sensors with intelligent software processing "SPC"
e	Main utilization:	Research	Research and Industry	Industrial production	Industrial production
f	Reliability:	Very high	high	Can be raised to acceptable level	Errors are minimized
g	Accuracy:	high	good	sufficient, fully human resource depending	sufficient, partly human resource depending
h	Hardware costs[c] (EUR):	2k to 50k + part	70k to 300k instrument	1 to 3 k for equipment 0.5 to 2 for 1 piece plate	5k to 30k machine outfit
i	Costs[c] per single test (EUR):	high to very high value of part + processing	high 200–600	little 10 to 70 (intensity and coverage by Almen Strip) 5 to 10 (intensity and coverage by Almen Round = uncommon))	does not apply
k	Trend of application:	Constant	Increasing	Fading ?	Increasing
l	Future development potential:	no	high	little	high
m	Standardization:	does not apply	partly (ASTM/SAE)	Almen Strip = extensive	no

Remarks:
[a] to give just a fragmentary idea
[b] X-Ray also used partly "destructive" (electropolishing) to compensate for the disadvantage of low penetration depth
[c] all monetary figures are very approximately due to the wide range of product/make variations (validity year 2002, 1 EUR ~ 1 US$)

idea and work on that. Then, the component design engineer's dream becomes true and thus, the peening process can become a fine machine tool. Results can be truly measured and the time of simulation combined with various rather complex activities are past. The benefit would be an improvement of part functional safety and a reduction of quality control steps. Of course, total costs must be kept in relation. So far, the Almen test procedure is today's superior technique, but other quite different methods to evaluate or to inspect residual stress are known as listed in table 1.

3 The Plate Deforming Technique "PDT"

Shot peening has been introduced about 80 years ago and in 1943 has become a companion that up to now could not have been separated from any kind of peening process. It is the donation of Jo Almen who suggested to use a flat plate for testing the effect of a shot bombardment, just by measuring the curvature resulting when processing one side only. This simple plate has been blown up to a world wide success with a yearly consumption well over 5 million pieces. In standard configuration, brilliant as the idea is, even more astonishing is the fact that in the past 60 years, this technique remained nearly unchanged and has nothing left from its importance to industry and research. Henry Ford with his T-model motorcar was not as lucky as Mr. Almen was with his A/N/C strips, The T-metamorphosis is still in progress. Not so the petrified Almen [1] technique (Fig. 1).

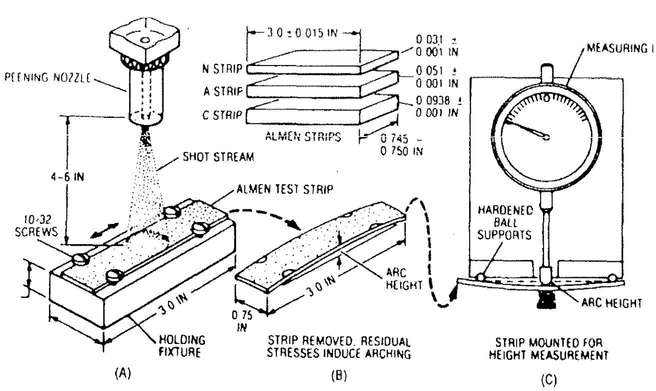

Figure 1: Typical Almen procedure

There are various reasons for that:

a) The procedure is very simple, hardware costs and evaluation time can be defined together with machine down time costs. The exact costs can be worked out (table 2).
b) The process specific behavior of the specimen can be highly consistent. It can be a reliable measure for comparison with effects on actual work-piece.
c) The application and standardization comes from a national high tech source that includes design, manufacturing and post treatment and is the basic of all international regulations.
d) The workshop activity and paper work in all companies are well organized and routine in every respect.

e) Standardization is worldwide on a top level.
f) The process can be done by specifically trained, reliable persons. No basic background is really required.
g) Plates can vary in size, shape and thickness as well as in material. For example, for small hole application, a sectional peening treatment is even possible.
On the other hand, some limitations have to be mentioned:
a) A certain weakness [2] of the Almen strip system is documented in the literature and all experts dealing with this subject are aware of that.
b) No direct correlation exists between an Almen evaluation testing procedure and the actual work-piece.
c) No real measurements of residual stresses in surface layers of actual work-pieces are done. This is the outstanding disadvantage of the Almen principle.
d) It needs quite an effort to prove the comparability of the process for a particular part with the Almen procedure run.
e) As for peening processes, more and more expensive machinery becomes common. Machine down time costs, just for the time consuming Almen strip procedures, must be taken into consideration.
f) The standard regular Almen strip is not ideal for an automatic handling and processing. Simple handling and simple installation is the domain of the so-called Almen Round [3].

4 X-ray Diffraction "XRD" (and Variations)

A true recognition of residual stress in MPa up to a depth of a few microns is offered by this highly scientific machine that can cost between 70 and 300 kEUR or kUS $. The function on the basis of X-rays is quite complex. For a comprehensive understanding, we would have to go into details which is not possible here.

The instrument is very practical [4, 5] and widely used in universities and research centers. It has the outstanding advantage that true stress figures can get evaluated. However, there are also disadvantages that should be mentioned:

a) Due to physical laws similar to optical in/out race of the rays (Fig. 2), the front end key device has a certain minimal size and geometrical shape. And this is a handicap for measure-

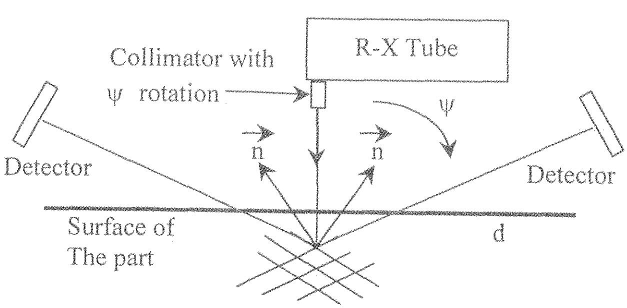

Figure 2. XRD-principle (STRESSTECH)

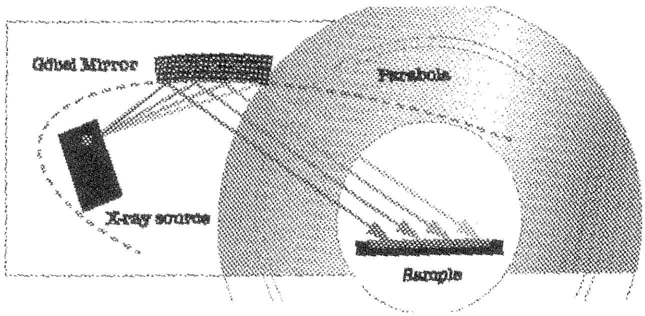

Figure 3. XRD-principle (BRUKER AXS)

ments on many typical structural parts, e.g., aircraft parts with small radii, small holes or extreme shapes. However, other principles do exist (Fig. 3).

b) The penetration depth of normal instruments is very small - only a few microns [μm] - and also the exposure time required can be quite long (over minutes).

c) Such an instrument requires a skilled operator, but X-ray diffraction scientists are rare and a short training course is definitely not sufficient to reach the necessary scientific level.

A prosperous attempt, especially in the field of shot peening has been made by a US-industrial group [6], but did not pursue this concept due to the rather small potential market that was expected at that time. At present, there may be a dozen companies worldwide which offer adequate XRD machinery to be used for peened parts. However, the application is rather in research and not really in production and re-conditioning. Since improvements in this line are usually made in small steps, over the years, the peening engineer might become more familiar with XRD than he is at present and was in the past.

Similar to the standard XRD is the neutron diffraction method [7]. At present, this method which is still under development is used for very special applications, but could be a highlight towards improvement in residual stress evaluation for peening processes. The penetration depth in neutron diffraction is much greater than in X-ray diffraction.

4.1 Barkhausen Noise Analysis "BNA", Eddy Current

A very nice and not too complicated method [8] makes use of the materials magnetic properties and elastic strains/stresses. The so called Barkhausen noise signal is the answer of the material to a magnetic field which is applied on to the surface of the part by the sensor. This signal is a function of hardness and residual stress state of the part and can be correlated. The BNA can characterize the peening process applied and could be standardized. The advantage of a relatively deep penetration of up to 1 mm is worth to mention, but also the severe disadvantage that it is impossible to examine non-ferromagnetic materials.

The practical measurement is very simple, various kinds of sensors even for holes down to less than 10 mm in size are possible. There are portable monitors, bigger installations and automatic devices. The BNA is well established in the automotive industry, e.g., for grinding processes, or examination of suspension springs. It should be possible to introduce this system also extensively for shot peening application. Also "Eddy current" technology should be taken into consideration [9].

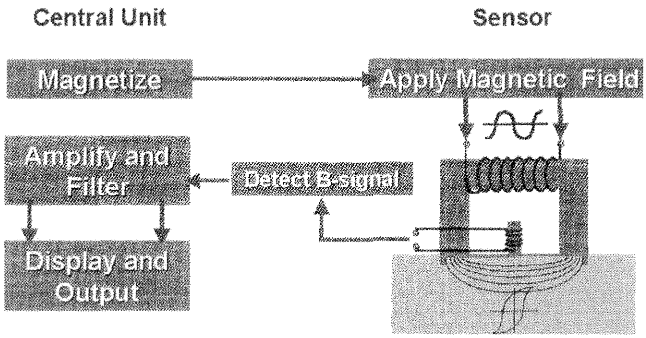

Figure 4. BNA-principle (STRESSTECH)

4.2 Statistic Process Control "SPC"

If you process an Almen plate with a conventional peening machine, it is similar to a blacksmith job. There, you bring a piece of steel into the desired shape. Hammering and examination and hammering again. Finally you get what you want, the same process for the next piece. If you are more advanced you will use a forging die and then, all the pieces processed by this tool are identical. From time to time you can examine a piece, also you can estimate the time of the next examination, even the expected lifetime of the tool you can work out from statistic calculations [10-12].

The same idea applies for a modern high-tech peening machine. Such normally CNC controlled machines with closed loop outfit for pressure and media flow, also multi-axes CNC movement and with various sensors e.g. for nozzle identification, air flow and shot storage

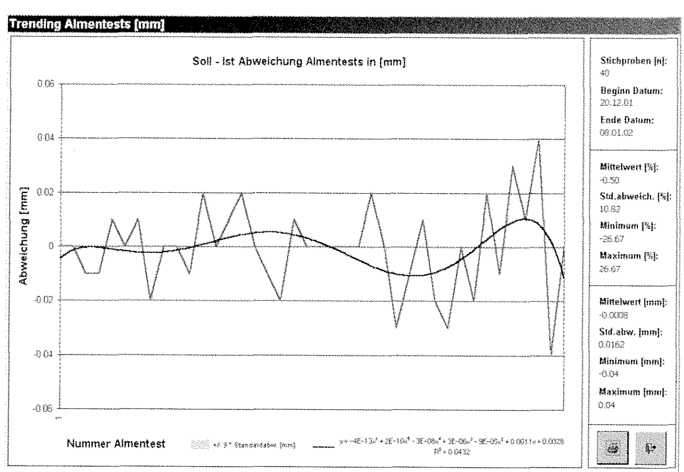

Figure 5. Almen statistics (BAIKER)

facilities. The software handles sensor signals, stores data, calculates functions and prepares messages and communicates with the operator. Behind all this, a software manages all the statistic procedures as illustrates in Figure 5 and informs the operator about normal operation or is involved in service recommendations or emergency actions. Following international trends, such equipment can easily be connected via standard protocols to selected networks and communicate, e.g., with the supplier in case of exotic failures.

In practice, such a machine allows a set-up/programming according to specifications or stored job routines. Once created, the machine will guide the operator through the full job. It monitors all sequences and processes, will also tell when, e.g., a manual intensity check [13], say an Almen plate procedure, has to be performed. Even such a check can be done automatically, e.g., when using Almen Round technology.

So here the machine is self controlling, once a parameter is stored, e.g., peening intensity, it can be repeated and even varied, or several different intensities and coverages can be stored and reproduced when ever necessary. Together with the automatically requested intensity checks or even calibration/service recalls, the machine has highest reliability and has a very high produc-

Table 2: Time evaluation (conventional Almen versus SPC)

TIME EVALUATION SHEET SHOT-PEENING for Almen-Processes (Air operated peening machines)		Datum: 2002-May Source.: (Name, Company) general example	
Job description: Intensity and coverage machine set-up procedure			
Shot peening machine A = A comparatively simple peening machine with manual media feed and pressure control			
Kind of work piece	Simple	Complex	Remarks
Example, designation (GE, CFM, PW, . .		2nd St LPT Disk 80C2	
Time spent for set -up of measuring devices, time for actual processing, strip handling, arc high determination, clearing away and paper work [h]		up to 3 hrs	
Effective process time for treating one original work piece after the set up [h]		0.5 hrs	
Part specific intensity verification after . . hours (e.g. company typical)		4 hrs	
Shot peening machine B (SPC equipped) = A modern CNC machine fully controlled with closed loop technique and pre set parameters, statistic process controlled			
Kind of work piece	Simple	Complex	Remarks
Example, designation (GE, CFM, PW, . .		2nd St LPT Disk 80C2	Same job as for machine "A"
Time spent for set up of measuring devices, time for actual processing, strip handling, arc high determination, clearing away and paper work [h]		max 1 hr	
Effective process time for treating one original work piece after the set-up [h]		0.2 hr	
Machine general intensity verification after . . hours (ev. calculated by machine)		8 hrs	
Remarks: Above figures may vary widely depending on company/skill of labour/equipment			

tion availability. Practical experience shows that with the Statistical Process Control, one single intensity test per 8hrs shift is absolutely acceptable. Obviously, such a technique will reduce machine running time and overall costs considerably (table 2).

5 Conclusions

Although politics and philosophy should not be touched here, it seems to be a fact that highly civilized countries can only economically survive, if there is a continuous, even very small advancement to be noted. Shot peening as a microscopic part in the industrial field is not yet on its peak. Its subdivision "Residual Stress Evaluation" still is in a high technological "vacuum". And this should be reduced by innovations and contributions of the present and future generations.

Regarding the matter "Future development in Residual Stress Evaluation", it seems that the Plate Deformation Technique (Almen) cannot be replaced in the near future due to the high technical and administrative level established in the key industries. Because of the high efforts in budget and personnel necessary to introduce new technology, no fast change in present situation can be expected. But then again, a development is imperative and shall be a challenge to human resource.

6 References

Only a few directly text related references are mentioned here. For more information, the internationally accessible documents can be traced, e.g., under - www.shotpeener.com -

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