INCREASING DYNAMIC STRENGTH OF MECHANICAL PARTS BY SHOT PEENING METHOD

Biljana Marković, B. Sc.[1], Prof. Dr. Eng. Momir Šarenac[2]

VZ"ORAO"- Bijeljina, BiH[1], Mechanical Faculty - S. Sarajevo, BiH[12]
e-mail: biljamarkovic@yahoo.com[1]
e-mail: mas.f.ssa@paleol.net[2]

Summary:

Load-bearing capacity calculation of mechanical parts is related to establishing of operating and critical stresses. Establishing of critical stresses is related to dynamic strength. Therefore, a great attention is paid to the researches of dynamic strength. One of often-applied methods for increasing dynamic strength of mechanical parts is shot peening process by stream of balls, which is the subject of this paper. Appropriate theoretical and experimental researches of possibilities for increasing dynamic strength of parts by this process were performed. As to achieve optimum results, it is very important to establish the parameters of the process itself. By comparative analysis of dynamic strength of parts being or not strengthened by shot peening method with stream of balls, applicable results of interest for engineering practice were obtained.

Key words:
Dynamic strength, blasting by shot peening, experiment, results analysis;

1.Introduction

When calculating dynamic strength of mechanical parts, factor of safety is shown as ratio of operating and critical stresses, i.e. states of stress in which parts are functioning correctly relative to the states in which their further functioning is not possible.

Critical states of stress, i.e. critical stresses, in the first place, cause destructions, i.e. too big elastic and plastic deformations, as well as fatigue fractures. Such fractures are caused by variable stress states, and at the quantization of analogous accidental stress change, the parameters that are essential for fatigue should be retained. Primarily, these are change magnitude and the number of stress changes, which should be selected, classified, and the number of occurrence of each change magnitude should be established.

Mechanical process of strengthening by shot blasting with stream of balls directed onto the surface of mechanical parts is well known production method, which is utilized as an useful mean for improving resistance of produced parts to fatigue failure, i.e. for improving the characteristics of dynamic strength.

2. Strengthening by shot peening

Strengthening by shot peening is clearly defined mechanical process, which is carefully controlled, and which can provide continuous results, in accordance with the needs of current production. As the result, improved fatigue life of many parts is provided, and as such, the process is used as the common one. Generally, strengthening by shot peening increases fatigue life of any part subjected to bending stress or twisting stress, but has a little effect to axial stress caused by compressive stress or tensile stress.

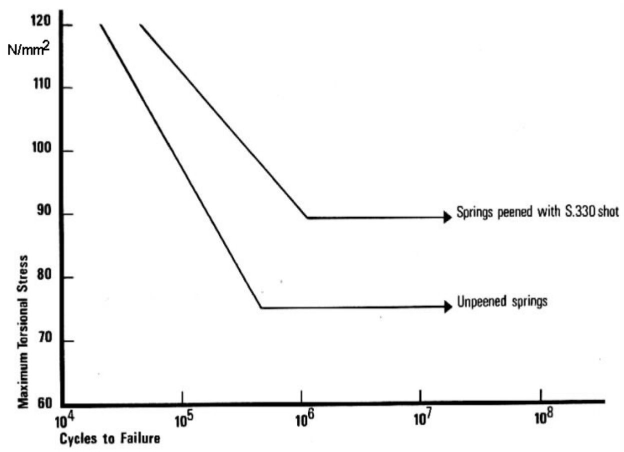

Fig. 1. Illustration of life change of blasted and non-blasted elements

The list of parts and products that were strengthened by shot peening with resulting improvement is long, and the list is continuously extended as researches are carried out (see fig.1). However, this process does not represent the mean by which all defects, caused by poor design or poor techniques in preceding processes, will be corrected.

In all new applications, the shot blasting should be carefully studied, in accordance with the nature of specific problem, and generalization should be avoided, as much as possible. The shot blasting process requires precise selection of blasting parameters. Correct selection of blasting parameters should be based on non-destructive testing of surface layer, taking into account adequate criterion of mechanical properties, e.g. fatigue period. In practice, the most frequently used criterion is the criterion of satisfying the requirements for blasting intensity by measuring the bending of Almen Test Strip.

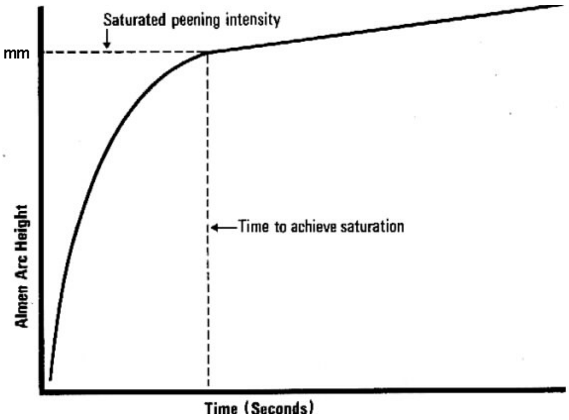

Fig. 2. Illustration of Almen arc height and exposure time ratio

The graph in figure 2. shows how blasting intensity (Almen arc height) increases by increasing the time of exposure. It is important to point out that the time of exposure depends on the hardness of material being exposed to the blasting (longer for materials with hardness more than test strip, and shorter for materials with hardness less than test strip). In practice, this is calculated during previous shot blasting and fatigue test, in order to establish optimum conditions for shot peening for each individual application.
Many authors in this field dealt, and are dealing with the analysis of the factors affecting the change of surface layer characteristics of strengthened parts. However, the systematization is very difficult, due to numerous parameters and variable limit conditions of most tests, as well as different geometry of test samples, different characteristics of stream, different methods of measuring and testing. The following figure shows qualitative assessment of interrelation of blasting parameters relative to the change of surface layer properties of strengthened part, which is based on supplement of known and published papers.

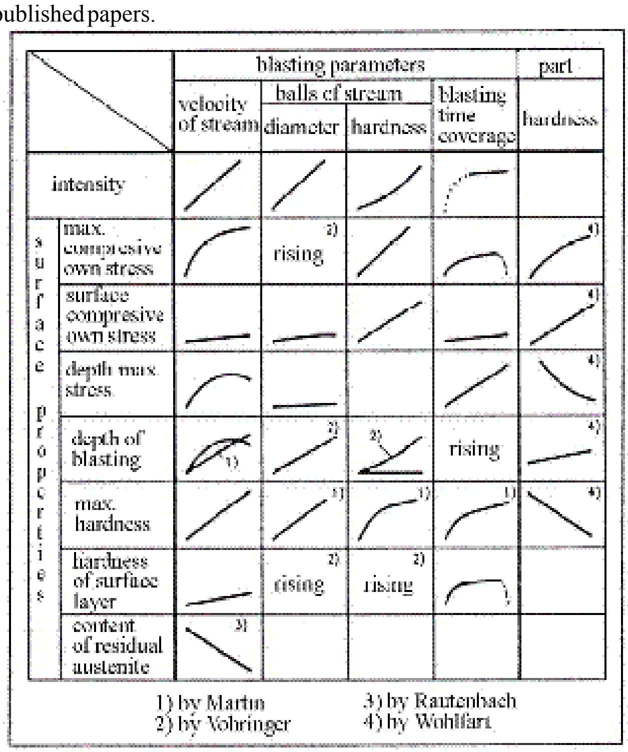

Fig. 3. Influence of shot blasting by stream of balls and hardness of shot blasted part to the change of part properties

3. Experimental tests - identification

In order to research the improvement level of dynamic strength of mechanical parts by shot peening method, experimental tests of some groups of samples, specially designed for the needs of such tests, and specially chosen material, were performed in VZ "ORAO".
Such tests were necessary due to the requirements for mastering the production of disc I stage LPCR (Low Pressure Compressor Rotor) of MM-17 engine, of INCONEL 718 material, which was chosen as alternative to the original material.
Experimental tests are conceptualized so that, based on Program of the tests, which in details describes each phase of the test process, optimum parameters are established, i.e. blasting intensity, by testing dynamic strength of samples that are shot peened and those that are not, by measuring micro hardness and structure of strengthened layer, and the coverage of strengthened surface.

The course of experiment includes the following steps:

1. - Definition and specification of test equipment,
   - Production of test samples,
   - Design and production of adequate tools;
2. Establishing of shot blasting effects to groove flank and root of the sample through Almen test with three different blasting methods (without deflector, with triangle or cone deflector);
3. Selection of shot blasting method, (reject all methods that have lesser shot blasting effects, lower intensity, and non-homogeneous coverage);
4. Shot blasting of test samples by selected method with three blasting intensities: I_1= 0,15A, I_2=0,22A, I_3=0,3A;
5. Testing of dynamic strength of:
   - non-blasted samples,
   - blasted samples by intensity I_1,
   - blasted samples by intensity I_2,
   - blasted samples by intensity I_3;
6. Statistical data processing;
7. Testing of micro hardness and structure of the surface layer;
8. Selection of optimum intensity and time of shot blasting.

When resolving the design of the sample itself, all aspects important for testing (type of testing device, shape and design of critical part of disc, conditions and mode of shot blasting, as well as reference researches of foreign authors) were considered. Based on mentioned considerations, the type of sample, as shown in the following figure, was adopted.

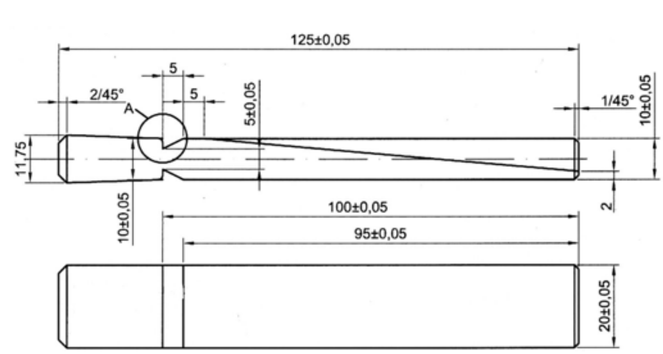

Fig. 4. Test Sample

Also, for the needs of positioning samples onto test device (vibrator), a fixture was designed, as well as a special fixture for positioning sample onto the machine for shot peening by the stream of micro-balls.
Regarding the equipment for shot blasting, "SCHLICK" injection system is used, and testing is carried out on a vibrator by cold fatigue test – the method of free oscillations. The vibrator is a part of multi-purpose equipment made by Brüel & Kjaer, which is also used in engine overhaul,
The method was mastered in VZ"ORAO" as the method for establishing dynamic strength of TMM (turbojet engines) blades in laboratory conditions, where comparative methodology, applied by Rolls-Royce (RR) was used as a base.

4. Experimental testing - performing

In accordance with Program of experimental tests, after the first step, the most favorable shot blasting variant (see Fig. 4), based on the analysis of effects, i.e. blasting intensity (bending of Almen Test Strip) and assessment of coverage of blasted surface, was selected, Three sets of test samples, 10 pc. each, with three different blasting intensities, were blasted by so selected method.

Then, dynamic strength test was performed. A series of experiments were previously performed on different test samples of blades produced at RR. The results were neither published nor were entered into data processing. However, they were used as a base for making procedure for establishing basic parameters in performing dynamic strength test, which is as equally applicable to different types of blades as to the other types of samples.
At this, it proved that the biggest problem was establishing the moment of sample fracture, i.e. the parameters which define it. It is possible to find more definitions of fracture (appearance of initial crack) in literature, defining the fracture from the moment of crystal structure disturbance to rough defining of fracture as a visible crack.
The fact that body which oscillates by natural (resonance) frequency remains in that frequency until the moment when dynamic strength level reaches the critical value of dynamic strength, i.e. until certain number of cycles and load level is reached is used in dynamic strength test.
In these tests, the first occurrence of degradation of amplitude and oscillation frequency, which occur simultaneously are determined. The check of amplitude and frequency "stability" is carried out every 5 minutes.

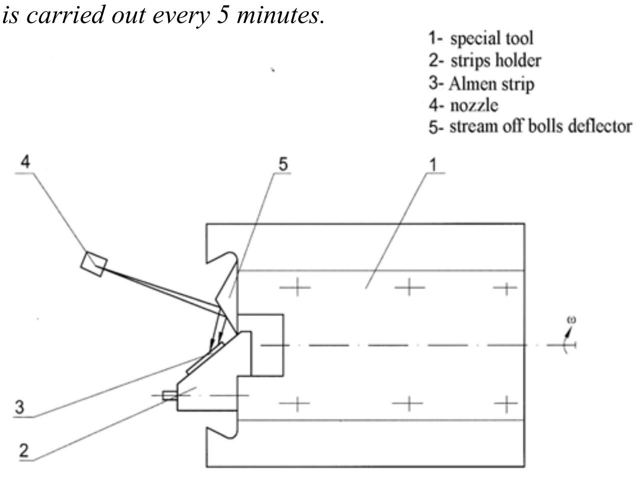

Fig. 4. Selected method of shot blasting

Basic parameters of dynamic strength are:

1.Clamping force (torque)

Whether real, operating or experimental test conditions are in question, clamping force (torque) affects natural frequency of sample oscillations. It was established [2], that with increase of clamping force in the zone of clamping natural frequency gradually starts tending to stable value.
In order to determine "stable frequency range", experimental tests of frequency – clamping force dependence were performed with samples clamped in a hydraulic chuck and in a mechanical fixture.
Based on experiments, the diagrams of clamping force – frequency, clamping compression – frequency were made, and based on the diagrams, it is possible to determine the clamping force so as to suit stable frequency range.

2.Cycle duration t_C

$t_C = 30$ *min, (determined).*

3.Load level Af

By performing a series of experimental tests, it was determined that by increasing "Af" level the number of cycles that sample could endure was reduced, and vice versa, by decreasing "Af" level sample strength was prolonged, i.e. the sample could "run" more cycles. By adjusting "Af" level to lower or higher value, the amplitude of the sample oscillation increases or decreases, which directly affects dynamic strength of the sample. Based on numerous trial and experimental tests, "Af" level = 0,15 mHz was established. Load level is expressed in mHz and it determines value of dynamic stress of sample trough amplitude and frequency, while time t represents minutes the sample endured in the last load level.

4.Frequency f_R

Assessment of frequency range for the first tone of bending oscillations was performed simultaneously with determination of clamping force. For detecting natural frequency of sample for the first tone of bending oscillations, Brüel & Kjaer equipment was used, and frequency range of 720-780 Hz was determined.

5.Expected amplitude a_R

For given load level and determined frequency, the amplitude of oscillation could be calculated a_R:

$$a_R = C / f_R \text{ , mm,}$$

where:

a_R – calculation amplitude (mm),
C – load level factor (mHz), "Af",
f_R - resonance frequency (Hz).

6.Initial time of fracture t_P

It is expressed in minutes, and represents initial time of sample fracture (already defined).

7.Critical time of fracture t_K

This is a parameter whose definition is possible only as the result of experimental analysis. After a series of experiments and trials, critical time of fracture was defined, expressed in minutes, which represents the critical moment of sample fracture. This is sample strength expressed in time in the moment when initial crack, 1-3 mm deep, is possible to be noticed by penetrant powder inspection. During trial tests, it was established that critical time t_K is suitable factor for expressing dynamic strength time on existing configuration and equipment on which sample dynamic strength was tested.

8.Duration of fracture Δt

Represents the time from the moment of the beginning of fracture to the critical moment of fracture, i.e.

$$\Delta t = t_K - t_P \text{, min.}$$

9.Drop of frequency, Δf

This is frequency change from the level of resonance frequency for a given sample, in I tone of bending oscillations, to the moment of reaching critical moment of fracture, i.e. Difference between resonance frequency f_R and the frequency in the moment of fracture t_K.

10.Number of cycles, N

It is determined on the basis of critical time t_K and resonance frequency f_R of sample, by approximate expression :

$$N \approx 60 \, x \, f_R \, x \, t_K, \text{ in millions of cycles.}$$

11.Description of fracture –

The results of dynamic strength test of sample to fatigue is accompanied with description of sample fracture, with basic information: crack position and crack depth.

The results of dynamic strength test for one group of tested samples (shot blasted by intensity I_2) are given in the following Table.

Item No.	Sample No.	IF frequency f_R [Hz]	Testing		MF				FRACTURE			
			c [mHz]	deviation ± 5%	tp [min]	ti [min]	Δ t [min]	Δf_1 [Hz]	A_f [mHz]	N_{MF}	t_{Af} [min]	Description of fractures
1.	2	3	4	5	6	7	8	9	10	11	12	13
1.	OI2-40	755	0,151	0,6	325	330	5	16,7	1,661	$14{,}722 \cdot 10^6$	30	In sample groove
2.	OI2-39	772,4	0,154	2,6	370	372	2	29,2	2,008	$17{,}147 \cdot 10^6$	12	-
3.	OI2-38	746,9	0,149	-0,6	370	373	3	21,3	1,942	$16{,}581 \cdot 10^6$	13	-
4.	OI2-37	750	0,150	0	395	398	3	16,4	2,100	$17{,}775 \cdot 10^6$	8	-
5.	OI2-36	765,5	0,153	2,0	370	373	3	21,2	1,990	$16{,}994 \cdot 10^6$	13	-
6.	OI2-35	730,4	0,146	-2,6	340	345	5	17,6	1,753	$14{,}900 \cdot 10^6$	15	-
7.	OI2-34	724,2	0,145	-3,3	365	371	6	20,2	1,883	$15{,}859 \cdot 10^6$	11	-
8.	OI2-33	752,8	0,150	0	335	360	5	15,8	1,806	$15{,}131 \cdot 10^6$	10	-
9.	OI2-32	742,4	0,148	-1,3	370	373	3	15,6	1,930	$16{,}481 \cdot 10^6$	13	-
10.	OI2-31	730,3	0,146	-2,6	355	360	5	17,1	1,752	$15{,}555 \cdot 10^6$	30	-

TABLE T1

TEST RESULTS
Data on sample:

Description: SAMPLE, INCONEL 718
Designation: SHOT BLASTED I_2

After performed dynamic strength test,statistical analysis of the results was carried out, by Student's method for small sample groups, comparing each result with another. A conclusion was made as the result of the analysis, which indicates optimum shot blasting intensity out of three offered.

Metallographic testing and measuring of micro hardness of surface layer were carried out as one of the last steps of experimental test of dynamic strength.

Totally, 8 samples were tested, two from four groups of ten samples. Creating of criteria for selection of strengthening optimum parameters, based on testing results, requires the following facts to be taken into account:

- A small number of samples was tested,
- Samples were previously vibrated in order to test dynamic strength, which disabled differentiation of effects of strengthening by shot peening from effects of strengthening caused by vibrating.

5. Conclusion

Research of dynamic strength of mechanical parts, in this particular case of specially designed samples of INCONEL 718, i.e. the results obtained by experimental testing shows the following:

- Strengthening by shot peening causes significant changes in material surface layer;
- Strengthening effects depend considerably on the strengthening method;
- Strengthening by shot peening undoubtedly increase dynamic strength, but if shot blasting intensity increases, dynamic strength starts to reduce;
- Metallographic testing and micro hardness testing indicated the need for extending the volume of tested samples, in order to establish possible regularity of changes in surface layer caused by material shot peening.

Dynamic strength of mechanical parts, assemblies and subassemblies is interdisciplinary field where metal-physical, metallurgical, statical and theoretical strength has very important role. In spite of significant progress of research and testing methods, fatigue phenomenon is even today based on empirical methods.

Establishing of critical stresses is more complex than establishing of operating stresses, and is primarily based on experimental approach, by destructing a large number of samples of appropriate features. One of approaches to this problem is presented in the paper.

6. Literature

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