BALL PEENING MACHINES AND SOME ASPECTS OF BALL PEENING OF STEAM TURBINE BLADES

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ABSTRACT

The paper undertakes a problem of bearing-ball peening of large steam turbine blades and presents results of tests concerning surface layer condition and fatigue strength of 23H12MNF steel, that has been surface treated by polishing or bearing-ball peening. The tests have shown decrease in surface roughness, considerable increase in surface layer microhardness and compressive stresses arising in the surface layer after ball-peening. Modification of the surface layer condition by bearing-ball peening has caused increase in fatigue limit. The paper presents also schematic figure of machine for ball-peening of large steam turbine blades made in Rzeszów Technical University for steam turbine factory ZAMECH (Poland). This machine enabled to perform ball peening of blades up to 940 mm in length and 150 mm in width. There are four vacuum nozzles of special design, which are generating negative pressure and throw the balls at the surface to be peened. Machine control system make possible adjustment of individual working periods for every one vacuum nozzle and to get different degrees of strain hardening at different sections of the blade, according to requirements. Control of the process is performed periodically, using test blade provided with Almen's test strips. The peened blades have fatigue limit about 30% better than belt ground blades. Therefore ball peening process allows to eliminate previous belt grinding operation.

KEYWORDS

Bearing ball peening, large steam turbine blades, surface layer condition, compressive stresses, microhardness, fatigue limit, bearing-ball peening mechine.

SOME ASPECTS OF BALL PEENING OF LARGE STEAM TURBINE BLADES

The turbine blades are one of the most important and the most loaded steam turbine elements. They work under high-temperature conditions, in corroding medium and under high changing working loads, caused by hydrodynamics and centrifugal forces and vibration. Turbine blades resistance to these loads depends on surface layer condition of the blades and on finishing process which this properties creates.

Belt grinding is typical finishing process for large turbine blades. Though this process creates very good effects (low surface roughness, low bend losses, high fatigue strength) but its effects are insufficient for high-power turbine blades and it is necessary to use surface cold-hardening methods, principally to get increase in fatigue limit and safe life of blades. Generally applied cold-hardening process of small turbine blades is shot peening with very small glass beads (15 - 400 μm dia) - glass bead peening. That process must be realized with special machines and it is effective method to get increase in fatigue limit can reach even about 25% in relation to belt grinding. But yet on account of narrow ball stream and some construcional features of glass bead peening machines, it is difficult to treat large blade surfaces by this method. During glass bead peening of the large blade surface, glass bead stream, which is ejected from vacublast nozzle, is driven along special trajectory shown in fig. 1(a) and each blade sections are treated one after the other, during only one pass of the nozzle. On account of it, the surface layer properties (in particular microhard-

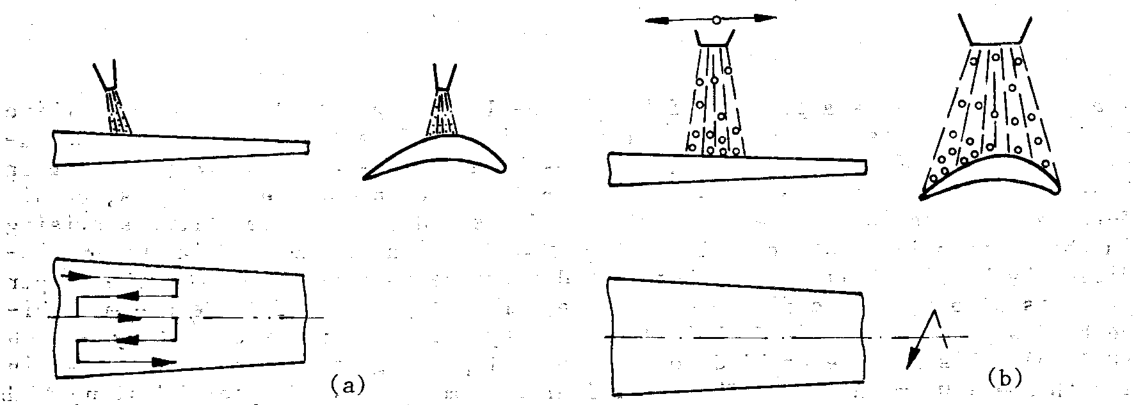


Fig. 1 Scheme of surface work-hardening by (a) glass bead peening, (b) bearing ball peening

ness and residual stresses) are irregular. Therefore this surface layer condition is not too good and causes decrease in fatigue limit. For that reason, the method of steel ball peening, presented in figure 1(b) is much better because stream of the balls covers full width of the workpiece surface and the blade is hardened gradually during many passes of the vacublast nozzles. In result surface layer condition and blade functional characteristic are much better. But treatment using the method presented in figure 1(b) is not possible if working stream contains glass beads, which would to have high energy at the moment they hit the workpiece. But one bead mass is very small, so stream speed would be very high, and distance between vacublast nozzle and cross-section dimension (diameter) of the vacublast nozzle cannot be too large. Therefore glass bead stream cannot be too broad and it cannot covers too large area of the blade.

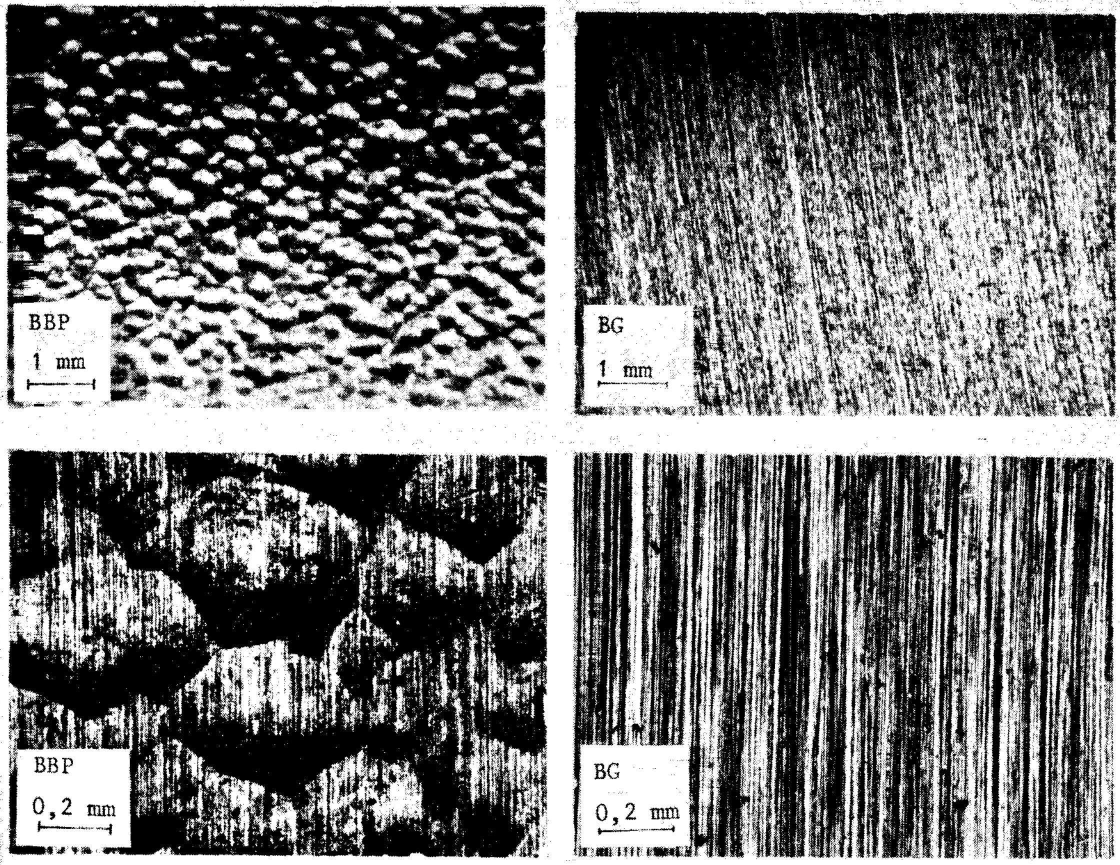


Fig. 3 Photographs of specimens made of 23H12MNF steel: BG - after belt grinding, BBP - after bearing ball peening

siderable difference between both types of the tested specimens. Into surface layer of ball peened specimens arise compresive stresses equal about -200 MPa and reaching down to the depth of 0,25 mm. After belt grinding also arise compressive stresses, but equal about -40 MPa and reaching down only to the depth of 0,05 mm. Degree of strain hardening, calculated in percentages as the ratio of surface microhardness increase to the core microhardness, was about 25% after bearing ball peening, and after belt grinding was insignificant - about 5%. Parameters of surface roughness for both types of specimens were very similar (R_a = 0,63 µm) but their surface stereometry was quite different as it has been shown in presented photographs. In photographs presented in fig. 3 one can see regulary pricked surface structure of ball peened specimens, whereas the surface structure of belt ground specimens is scrathed in the manner typical for abrasive machining. As shown in fig. 4 surface profilograms also have differences between both types of the surfaces. After bearing ball peening there are no sharp dimples on specimen surface which are clearly visible on the belt ground surface. By comparison between surface layer condition of specimens made of 23H12MNF steel after both finishing methods, it has been stated that the surface layer condition after bearing ball peening is better.

As shown in fig. 5 fatigue limit after bearing ball peening is about 10% better than after belt grinding. Results of the above tests caused that bearing ball peening has brought into practice as finishing method for large blades.

Simple shot peening of blade surfaces is also unsuitable method of treating because high working stream power and irregular form of particles cause surface microcracks, which resulted in blade properties decrease [1, 2].

Other typical methods of finishing cannot be used because blade forms are very complicated. So that, for gradually hardening of large blade surface layer with ball stream the balls must have higher mass and lower speed than glass beads used to glass bead peening and also they must have as small diameter as possible to get required surface roughness. Extensive tests, that were realized for many steel, titanium alloys and some metal alloys [7, 9] have shown that small hard steel balls are most suitable for this purpose. That may be 1 to 3 mm diameter bearing balls.

Bearing ball peening process is very similar to glass bead peening and the effects of these both processes are the same. Particulary is created hard surface layer with compressive residual stresses into it, and treated surface have characterictic pricked surface structure. Such surface layer condition, as is generally known, is the best for properties, particulary for fatigue strength and life of high loaded machine elements.

RESULTS OF TESTS

The typical big turbine blades are made of 23H12MNF steel. The specimens, that had been cuted out from blades made of this steel, were hardened by bearing ball peening, using 3 mm diameter balls accelerated in compresed (0,3 MPa) air stream. The specimens were peened for about 40 min., to achieve 100% covering. Then examination of surface layer condition (surface stereometry, surface roughness, residual stresses distribution and microhardness) has been carried out and its results compared with results for belt grinding finished specimens made of the same steel. The belt grinding was realized with alundum grinding belts of 380 grain size [7]. Microhardness measuring was performed by Vickers method, using Matsuzawa-Seiko hardness testing machine, under 1 N loading for 15 sec. The surface roughness was measured with Surtronic-2 profilometer, at 0,8 cut-off. Tests of residual stress distribution has been carried out by Waissman-Phillips method, using the special computer-aided measuring device, made in Rzeszów Technical University [3, 5]. Fatigue tests were realized basing on special speeded up method on electrodynamic vibrator ST 5000/300, according to methodology that have been detailed described in [4]. Results of surface layer condition tests are presented in figure 2, 3 and 4. Results that had been obtained have shown con-

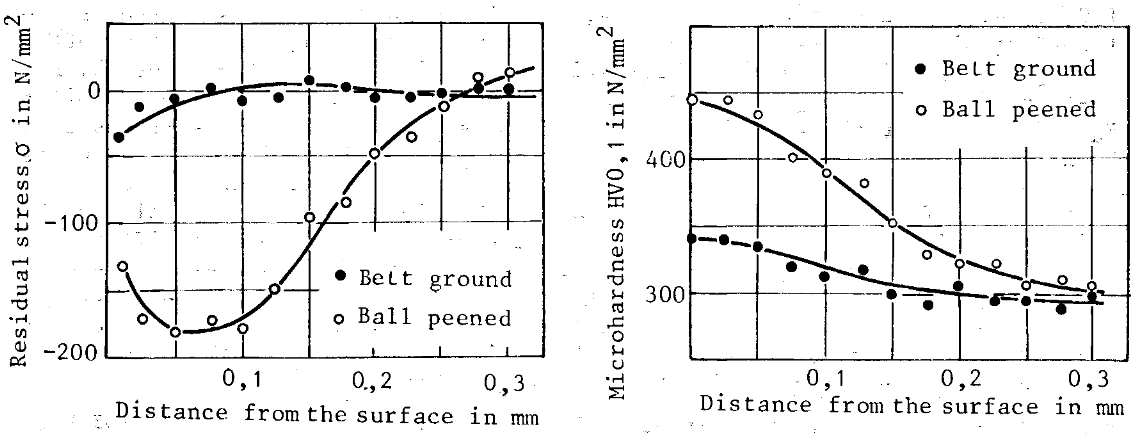


Fig. 2 Results of the tests of surface layer condition on specimens made of 23H12MNF steel

Fig. 4

Results of the tests of surface roughness on specimens made of 23H12MNF steel: BG - after belt grinding, BBP - after bearing ball peening

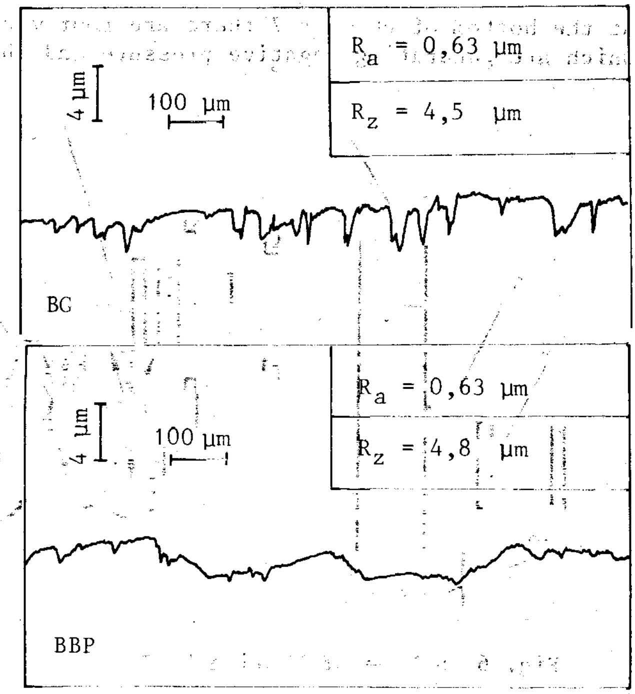
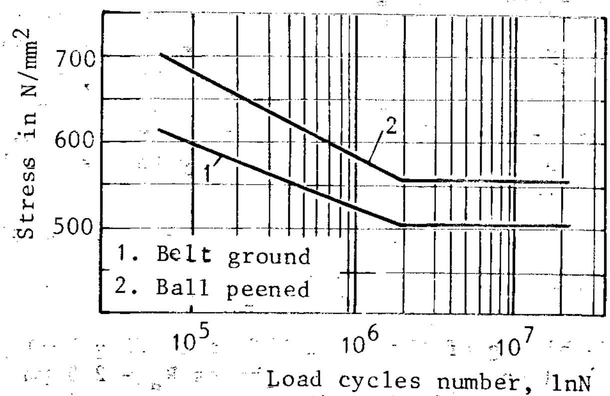


Fig. 5

Results of the tests of fatigue strength



BEARING BALL PEENING MACHINE

Bearing ball peening machine has been designed and made in Rzeszów Technical University. This machine, diagram of which is presented in fig. 6, enabled to perform bearing ball peening of blades up to 940 mm in length and 150 mm in width. Tips of the blade to be peened 1, are fixed in special chucks reaching to about 5 mm from the blade locking pieces. During peening the blade is rotating very slowly. Power from motor 2 is transmitted to both tips of blade synchronously by speed reducer 3, feed shaft 6 and two chain transmision units in cases 4 and 5. The blade and chucks are enclosed in chamber 7, that is provide with telescope sections. The chamber make slowly reciprocating motion and is driven from motor 2 by reducer 3, chain transsmision 4 electromagnetic cluth and lead screw 8. Distance and direction of the chamber motion are controled by two limit switches.

At the bottom of chamber 7 there are four vacuum nozzles 9 of special design, which are generating negative pressure and throw at the surface to be peened.

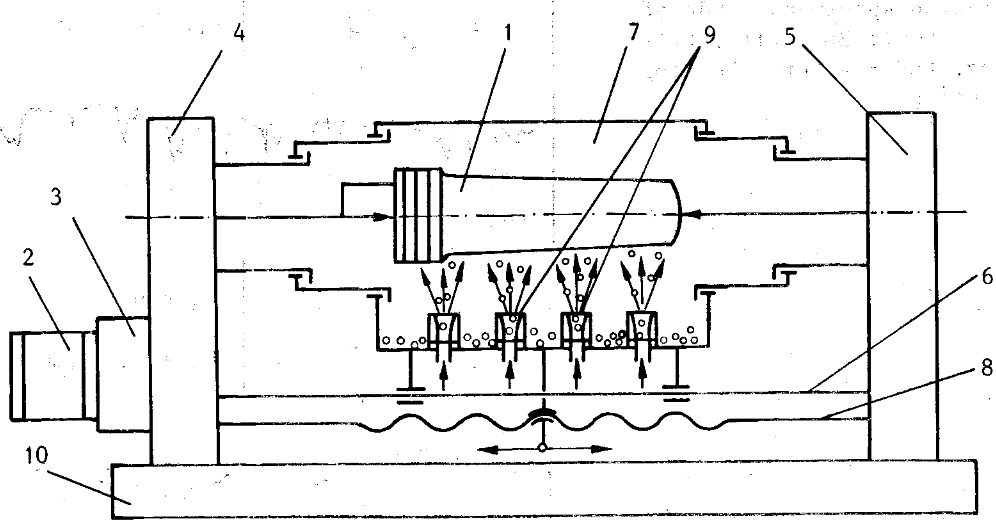


Fig. 6 Scheme of bearing ball peening machine

The distance from nozzles to the axis of rotation of the blade is selected so that its changing position has not considerable influence on effects of peening. Machine control system make possible adiustment of different working periods of every one of vacuum nozzles. It make possible to get different degrees of strain hardening at different blade sections, according to requirements. The machine is mounted on the base 10, and its vacuum nozzles are supplied from air compressor or from factory compressed air network. The machine runs at semi-automatic cycle and its operation is only to fix the blade to be peened and start up the machine.

The bearing ball peening machine made for steam turbine factory ZAMECH (Poland).

BLADE BALL PEENING PROCESS

Machining of the blade before bearing ball peening is quite standard, and is aimed to get surface roughness R_a = 2,5 μm at stress concentration places and 5 μm on remained surfaces. Convex radii must be equal 1 mm/min and concave radii 6 mm/min (double diameter of the ball). Before peening the blade must be degreased. Principal variables of bearing ball peening process are: air pressure, ball diameters, distance from nozzles to the surface to be peened and time of peening.

Results of blade ball peening tests have shown that optimum values of these variables are: vacuum pressure 0,3 MPa, average distance between vacuum nozzles and blade axis 160 mm, blade rotational speed 19 r.p.m., reciprocating motion speed 150 mm/min. As a working medium steel bearing balls of ŁH15 steel, 63 HRC, have been used in total amount about 9 kg. At these variables the time of peening securing 100% coverage of all blade surfaces with ball marks is from 20 to 50 min and depends on blade dimensions.

Because the balls are getting dirty with moisture and oil from compressed air and with metalic dust from blade surfaces, the balls must be washed in petrol after each 50 working hours. It is only weighty disadvantage of bearing process. But if the vacuum nozzles are supplied from air compressor or if supply air from factory compresed air network is specially cleaned, the balls must be washed very seldom; it depends on used air filters and blade material. Basing on practical experience, it was stated that as a working medium small bearing balls may be used very long (some years).

PROCESS CONTROL AND EFFECTS OF BEARING BALL PEENING

Bearing ball peening process control is performed periodically, using test blade provided with ten Almen's test strips placed on particular blade sections. The degree of surface coverage with ball marks is examined on every one blade with microscope or by comparison to roughness master. Every blade have to have 100% coverage of all surfaces with ball marks and blade surface cannot be cracked or scrathed. Blade surface roughness and surface microhardness are controlled periodically with profilometer and hardness testing machine.

The bearing ball peening machine presented in fig. 6 is used to work hardening of high power steam turbine blades. According to user's opinion, the blades peening with bearing ball stream have fatigue limit about 30% better than blades that have been finished by belt grinding. This result is better than results of the laboratory tests that vere carried out using specimens whithout notches. The result is better because really turbine blades have got more notches than laboratory specimens and therefore global effects of work-hardening is better. Similar effects are usually noticed in respect to very hardened machine elements which have construction and surface notches and which work under high changing working loads or vibration.

Despite long time that is need for one blade bearing ball peening, the productivity is satisfactory. Application of the bearing ball peening process to harden blade surface layer caused even elimination of belt grinding operation.

NEW GENERATION BEARING BALL PEENING MACHINES

Now the second bearing ball peening machine is under construction that will make possible to peen blades 1400 mm in length and 240 mm in width. That machine will be working according to the scheme presented in fig. 6, using ten vacuum nozzles to get shorten time of peening. The vacuum nozzles are placed chequer-wise to get better coverage with ball marks on the whole surface of very wide blades. In that machine vacuum pressure 0,5 MPa and as a working medium steel bearing balls dia 1,5 mm have been used. The other values of bearing ball peening process variables and process control system are similar to used in peening machine presented before. Basing on practical experience some improvements were made in design to get shorten time of peening, to get blade functional characteristic better and to get increase in fatigue limit of hardened blades.

In new, the third generation machine, that also will be working according to scheme presented before, some improvements were made in control system. That machine will be equiped with computer-aimed control of very process variables.

REFERENCES

[1] Korzyński M., "Kulkowanie strumieniowe kulkami szklanymi i łożyskowymi jako sposób poprawy wytrzymałości zmęczeniowej". Wytrzymałość zmęczeniowa części maszyn po wybranych sposobach obróbki wykańczającej. Zeszyt Naukowy PRz, Rzeszów, 1988.

[2] Korzyński M., "Wpływ wybranych sposobów nagniatania na zużycie ścierne brązu B555". Technologia obróbki przez nagniatanie. Mat. III KNT, Bydgoszcz, 1984.

[3] Łunarski J. and Korzyński M., "Automatisierung der Messung und Berechnung von Eigenspannungen in der oberen Schicht". Rationalisierung in Maschinenbau, Zwickau 1985.

[4] Łunarski J., "Porównawcza ocena własności zmęczeniowych w badaniach technologicznych". Technika Lotnicza i Astronautyczna, 3, 1981.

[5] Łunarski J. and Korzyński M., "Badania rozkładu naprężeń w warstwie wierzchniej elementów silników lotniczych". Technika Lotnicza i Astronautyczna, 1, 1980

[6] Łunarski J. and Zielecki W., "Possibilities of improving fatigue properties of machine elements by pneumatic shot peening. Conf. ICSP 4, Tokyo, 1990.

[7] Łunarski J. et al. "Zagadnienia technologiczne umacniania łopatek turbin parowych metodą pneumokulkowania". V KNT Technologia przepływowych maszyn wirnikowych, Rzeszów 1983.

[8] Korzyński M., "Zastosowanie nagniatania do poprawy własności tribologicznych części maszyn. Konstytuowanie cech warstwy wierzchniej metodami technologiczno-eksploatacyjnymi. Zeszyt Naukowy PRz, Rzeszów 1987.

[9] Korzyński M. and Dul-Korzyńska B., "Urządzenie do nagniatania dynamicznego powierzchni zewnętrznych przedmiotów walcowych zakrzywionych". Patent No 13907, Warszawa, 1989.

[10] Korzyński M., "Urządzenie do nagniatania dynamicznego powierzchni zewnętrznych przedmiotów walcowych". Patent No 139508, Warszawa 1989.

[11] Korzyński M., "Głowica do nagniatania dynamicznego powierzchni otworów kulkami łożyskowymi". Prawo ochronne nr 44093, Warszawa, 1988.