Finite Element Method of Structural Analysis of Shrouded Aero Engine Turbines

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***Abstract*-Turbo-machinery blades and discs work at high temperature and high stress environment, subjected to centrifugal loads and vibration of blades. Turbo-machinery clearances of modern turbines are generally quite small, leakage losses still contribute significantly to overall losses. To reduce losses shrouds are designed for turbines. Structural analysis is carried out for shrouded and non-shrouded blades using ansys and vibratory dynamic stresses are estimated. Shrouded blade has less vibratory dynamic stress and radial deformation. Goodman's diagram plotted which shows stresses are in design limits.**

Keywords– gas turbine blades, turbo-machinery clearances, tip losses, dynamic stress, shrouded blades.

I. INTRODUCTION

The design of a gas turbine powerplant is a careful balance of many interacting parameters. The ideal powerplant would be the most fuel efficient at its thrust, the most reliable, the lightest, the quietest and the cleanest engine, all made at the lowest cost. In reality, several design parameters are in conflict and attributes must be traded, one against another, to create the best blend of characteristics for the design task.

The optimum blend of characteristics for one type of aircraft may not be the same for another. For instance long range aircraft favor high fuel efficiency and low weight, with payload revenues being important and operating costs being dominated by fuel costs, whereas shorter range regional aircraft need an engine with lower acquisition cost and a greater emphasis on cyclic reliability and low maintenance cost.

One of the major losses that should be avoided in aero-engine is the tip losses [1]around the tip of the blade which adversely affect the overall performance and increases the consumption of fuel. The gasses that comes after the combustion of the fuel which escapes easily at the tip of blade as shown in Fig.1.The shrouds are designed that blocks the gas and reduces the leakage of the gas.Shrouds [2] also help in increase the natural frequency so that avoids no low order resonance occurs in operating range. During operation of blades, turbine blades rotates at high velocity nearly 1538 rad/sec, due to which centrifugal loads, bending loads from the gas that strikes the surfaces of the blades and vibration of blades due to above loads and mistuning effect of blades which results in the adjacent vibration causes the stress at blade root and disc . In severe cases which results in the breakage of blades and shutdown of engine.

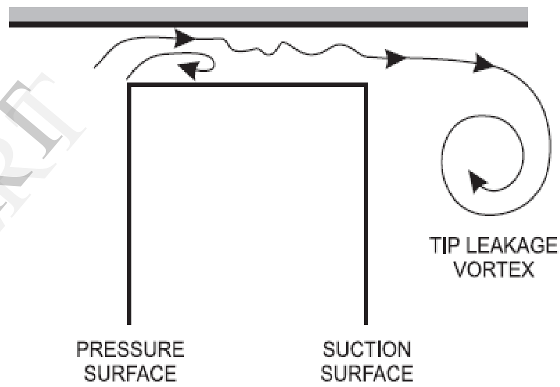

Fig.1. Scheme of the tip leakage over Non-shrouded turbine blades

From the failure analysis of aero-engine researchers concluded that nearly 30% [3] of failure takes place at turbine blades and discs which is due to vibration and fatigue. On the other hand to reduce the tip losses and to improve efficiency, shrouds are necessary to be designed for turbines. The design of shrouds is the critical task in aero engine because the design of shrouds which adds the weight on the blade. During rotation at high speeds due to centrifugal and bending loads the weight of blade becomes doubled and stress become very high at tip and root of the blade and at disc. Shrouds are designed that avoids the deformation of blade both in normal and tangential direction.

Shrouds that designed, performs the function of the dampers where shrouds constrain the motion of the blade not only in contact plane but also in normal direction of the plane. Dampers used in aero-engines which plays a crucial role in blade deformation and

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vibration and constrain the blade motion along contact plane. Both shrouds and dampers are used in aero-engines to alternate the resonant frequency of blades and at the same time to increase the aero-elastic stability.

Many authors[4-8] have analyzed the flow losses around tip of the blade. The present work is focused on the structural analysis of the shrouds in turbine blade and vibratory dynamic stress [9] of shrouds and non-shrouded blade.

II.DEVELOPMENT OF FE MODEL FOR AERO ENGINE TURBINE BLADES.

FE model isdeveloped by taking the solid model which does not contain any flaws and same was considered for the structural analysis. Fig. 2 shows meshed model of aero engine turbine blades which has 48568 elements of solid 183 of first order elements for one section of disc with blade.

Rotating components in aero engine is generally subjected to high stress due to blade vibration,centrifugal loads and thermal loads. Thermal loads that acts on the blade is found from the CFD analysis and same applied to model, symmetry approach is applied and bi linear properties of material UDIMET and NIMONIC nickel based super alloys [10], Angular velocity of 1538 rad/sec, density, poisons ratio[10], pre stain condition is applied to model. The turbine blade is considered UDIMET and NIMONIC nickel based super alloys material as per standards available in aerospace. Physical properties of blade material are given in table I and table II.

TABLE I.Physical properties of NIMONIC considered for FE model

Temp. in Celsius	Young's Modulus, Mpa	0.2% yield strength in Mpa	Ultimate Tensile Strength Mpa
20	212	960	1240
100	209	795	1185
200	204	800	1085
500	187	780	982
700	174	742	800
900	150	650	680

TABLE II.Physical properties of UDIMET considered for FE model

Temp. in Celsius	Young's Modulus, Mpa	0.2% yield strength in Mpa	Ultimate Tensile Strength, Mpa
20	205	1195	1570
100	198	1173	1485
200	191	1445	1455
500	184	883	1358
700	171	660	1247
900	148	542	880

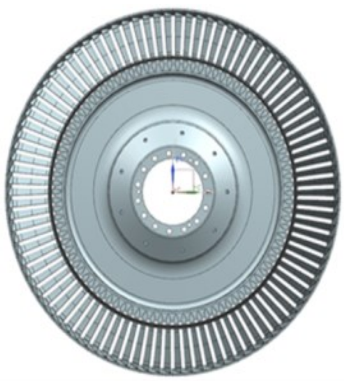

Fig.2Shrouded turbine blade with disc

Fig.3 Meshed FE model of single cut section with disc.

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III.RESULTS AND DISSCUSSION

A. CASE1.

Nonlinear static analysis of Meshed FE model of single cut section with disc of NIMONIC AND UDIMET

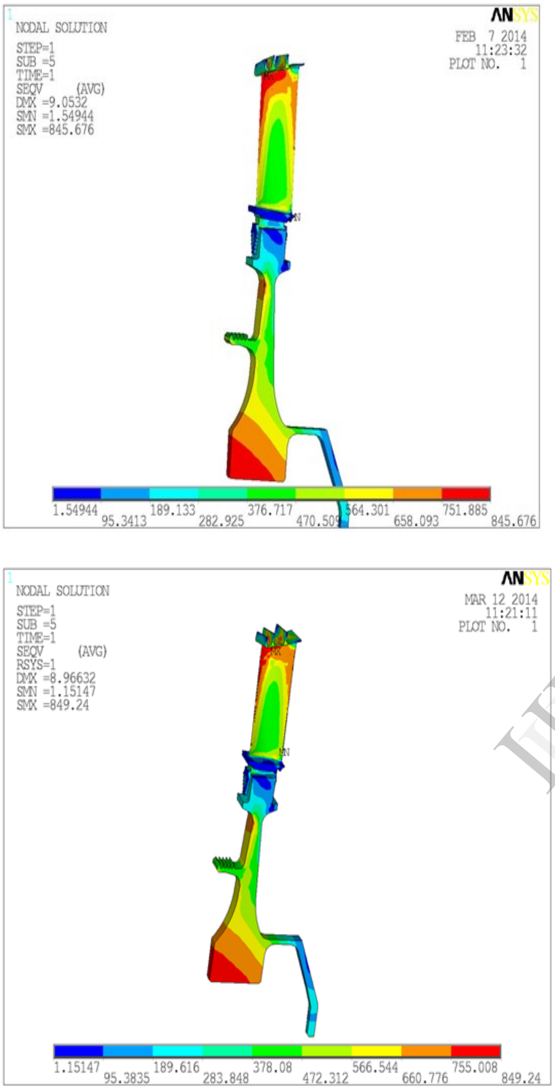


Fig. 4 FE simulation results of nonlinear static analysis of NIMONIC and UDIMET shrouded blades.

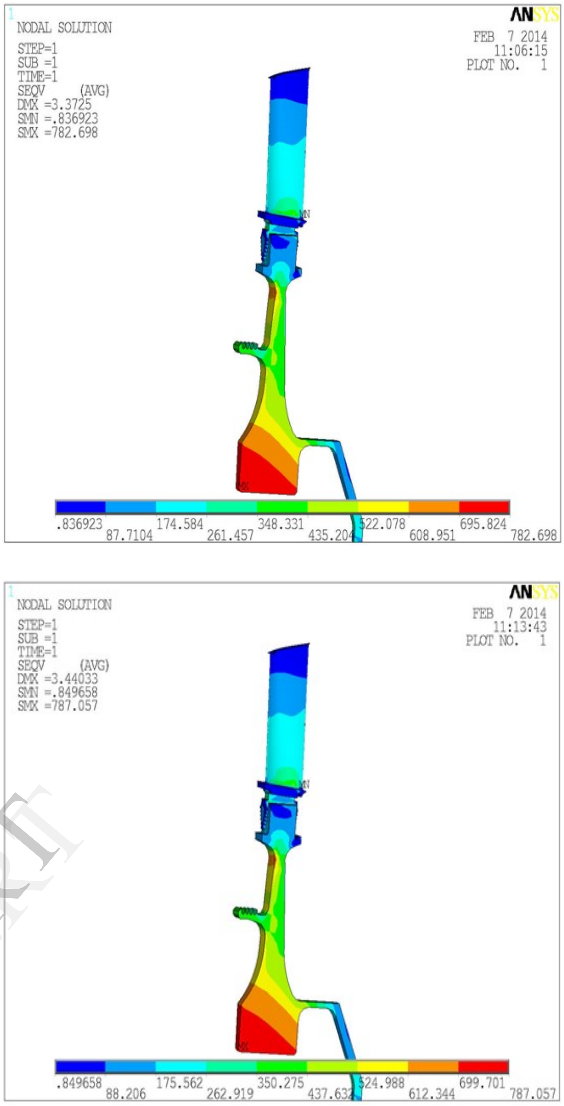
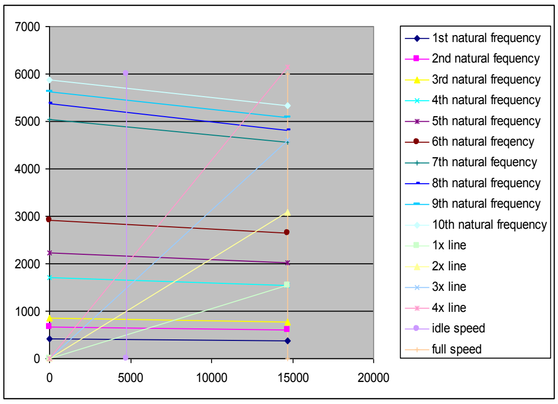


Fig.5 FE simulation results of nonlinear static analysis of NIMONIC and UDIMET non-shrouded blades

Fig. 4 and 5 shows the simulation results of nonlinear static analysis. Analysis is carried out by assigning nonlinear properties of both materials. Fig.3 indicates that maximum stress arises at the tip of blade due to shrouds which avoids the deformation of blade radially and minimum stress arises at the blade root. Stress obtained is lesser than yield value and FE simulation results, way of design approach and loads applied are in safe range.

B. CASE 2.



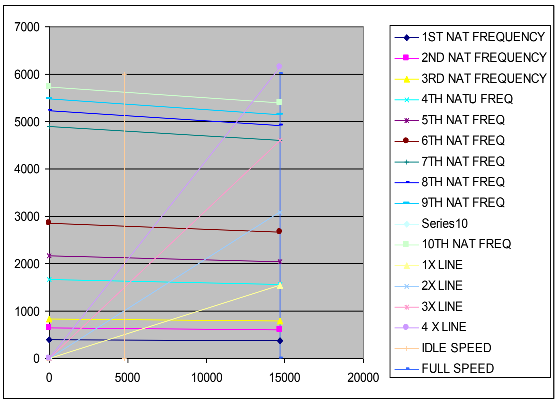
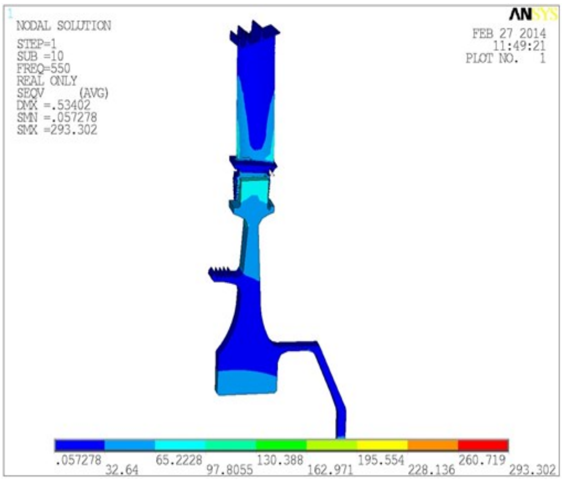
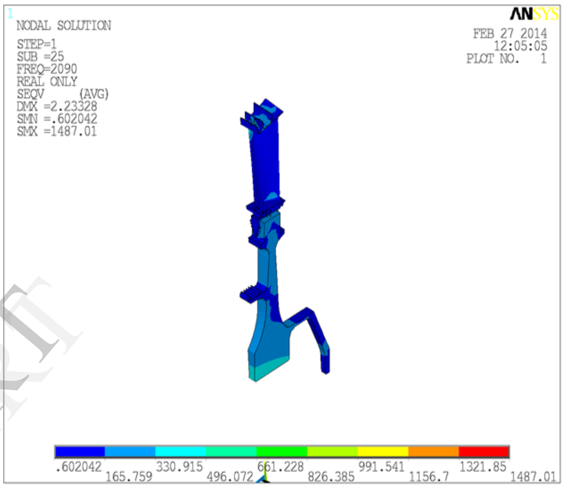


Fig.6 Campbell diagram plot from modal analysis of NIMOMIC and UDIMET.





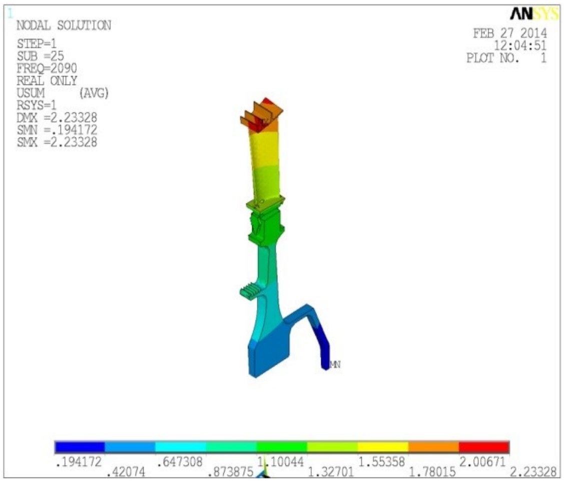


Fig. 6 shows the Campbell diagram plot that obtained from the modal analysis. Modal analysis is carried out for both material with and without temperature and idle speed of engine is taken as 5000rpm and full speed of engine is taken as 15000rpm and nozzle frequency is selected from experiment is 1538hz and frequencies obtained from the modal analysis are plotted. Fig.6 shows the intersection of lines with nozzle frequency which indicates the possibility of vibration of blades.

Harmonic analysis is carried out for intersection frequency.Results show that vibration of blades is less and radial deformation is less.

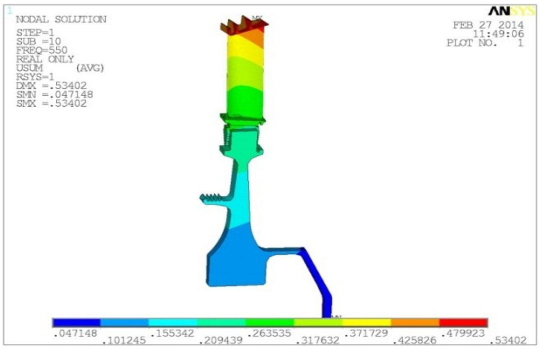
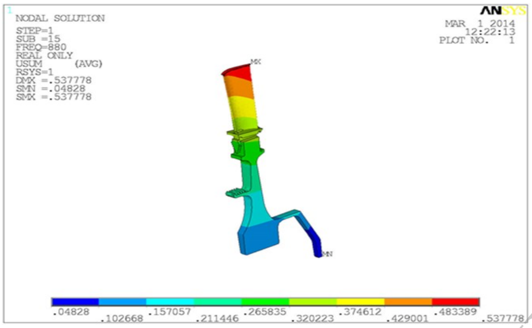
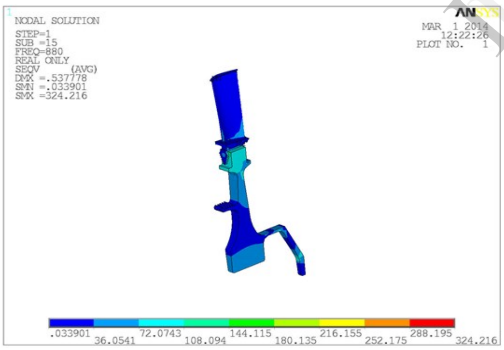
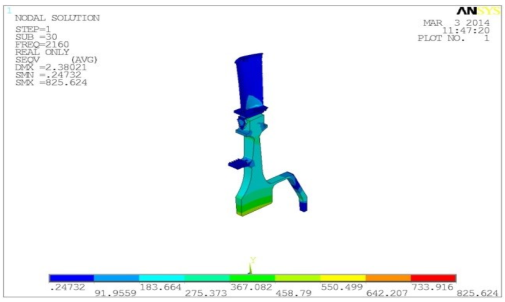


Fig.7. FE simulation results of shrouded blade HARMONIC ANALYSIS from Campbell diagram.







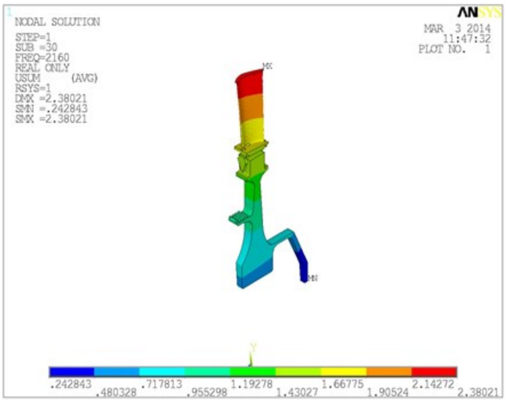


Fig. 8 FE simulation results of HARMONIC ANALYSIS of non-shrouded blade from Campbell diagram.

Fig.7and 8 shows that the hydrostatic stress and radial deformation is less in shrouded blades than the non-shrouded blades.

Radial deformation is considerably less in shrouded blades than the non-shrouded blade and vibration amplitude is less in shrouded blades.

Table III : Harmonic stress and deformation from harmonic analysis for shrouded blades.

Sl No.	Intersected Frequency In Hertz	Harmonic stress in Mpa	Deformation, mm
1.	550	293.302	0.53402
2.	570	385	1.85336
3.	1080	587.966	1.1459
4.	2010	1369.63	2.19502
5.	2090	1487.01	2.23

Table IV Harmonic stress and deformation from harmonic analysis for Non- shrouded blades.

Sl No.	Intersected Frequency, Hertz	Harmonic stress in Mpa	Deformation, mm
1	880	324.216	0.58
2.	920	870.26	2.23201
3.	2210	825.624	2.43021
4.	3500	1305	1.28
5.	4500	3505.25	2.86

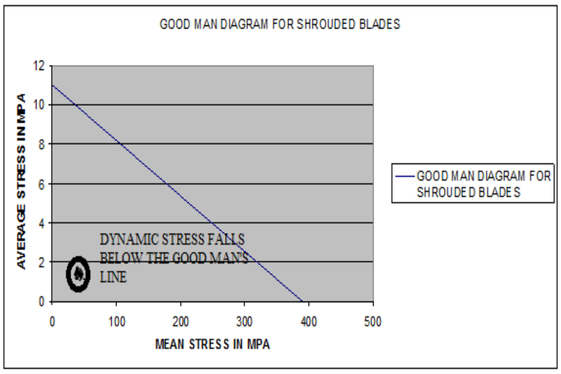
Table No. 3 and 4 shows the results of hydrostatic frequency and deformation for different intersected frequencies from Campbell diagram, which shows that shrouded blades has less hydro static stress and deformation during 108% engine speed condition than the Non-shrouded blades. Where non-shrouded blades have more deformation and have high hydrostatic stress and have chances of damage to turbines even at severe condition which leads to shut down of engine.

Case4. Vibratory dynamic stress of shrouded and non-shrouded blades.

From the research work carried out by J.S.Rao [9]of estimation of dynamic stress . Dynamic stress can find out by

$$\text{Dynamic stress}=\frac{1}{2\xi}*\text{peak stress.}$$

In above equation ξ represent the damping ratio,peak stress are found by applying the different pressure sections for trailing and pressure side, damping value taken for analysis is 2% and dynamic stress obtained for shrouded and non-shrouded blade is 41 MPA and 265 MPA respectively



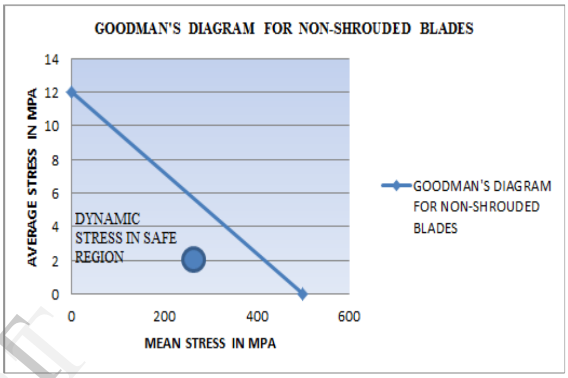


Fig. 9. Goodman's diagram for shrouded and non-shrouded blades.

IV.CONCLUSION

The effect of shrouds in turbo-machinery aero engine components to reduce the tip losses and improve frequency by structural analysis shows that shrouds reduces the radial deformation and avoids the movement of blade in normal direction. Good factor of safety is obtained for shrouded blades and from Campbell diagram plot the harmonic stress are in safe and radial deformation of blade is less. Vibratory dynamic stress of shrouds is less than non-shrouds which reveals that need of shrouds for turbo-machinery turbines.

REFERENCES

[1].Peng Kai Fan Ding, Yang Fan Fu Qiang Li Yong, "Active Generalized Predictive Control of Turbine Tip Clearance for Aero-Engines", Chinese Journal of Aeronautics Vol. 1.2013. pp 1-8.

[2]. Fan Jiang1, Zeng Weiwei, Wang Rongqiao, Shen Xiuli, Chen Zhiying research on, "Design and Optimization of the Turbine Blade Shroud", 2nd International Conference on Engineering Optimization Vol.12 2010,pp 1-5.

[3].B-D yang &C.H.Meng, "Vibratory Analysis of the Dampers and Shrouds Kinematics", ASME JOURNALS vol. 2. 2000. pp 1-6.

[4].S. Narasimha, G. Venkata Rao and S. Ramakrishna, "Stress and Vibration Analysis of a Gas Turbine blade with a Cottage-roof Friction Damper using Finite Element Method",14*th* National Conference on Machines and Mechanisms, pp 316-324.

[5].Aarash Rahmani, "Modal Analysis of a First Stage Blade in ALSTOM Gas Turbine and Comparison with Experimental Results", World of Sciences Journal 2013, pp 39-45.

[6]. Alexey I. Borovkov Igor A. Artamonov, "3D Finite Element Modeling and Vibration Analysis of Gas Turbine Structural Elements", ASME VOL 2, pp 1-18.

[7].Navaj sharif Shaikh, Prof. W.S. Rathod and Khalid Ansari, "Modal and Harmonic analysis of Turbocharger turbine using Finite Element Method", International Journal of Application or Innovation in Engineering &Management VOL 2, pp 6-9.

[8].J. KubiakSz. , G. Urquiza B., J. Garcı´a C., F. Sierra E, "Failure Analysis of Steam Turbine Last Stage Blade Tenon and Shroud", SCIENCE DIRECT journals vol. 1, pp 1477-1487.

[9.]J.S.Rao,K.C.Peraiah, "Estimation of Dynamic Stresses in Steam Turbine Blades Under Reverse Flow Conditions", 4th International Conference15-16 October 2008, Brussels, Belgium Altair Publication, pp 1-11.

[10].M.HetmanczykL. Swiadzba,B. Mendala, Journal Of Achievements In Materials & Manufacturing Engineering Vol.24 2007.