Reducing Paper Quality Variations by Predictive 3D Roll Grinding

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ABSTRACT

The predominant trend in paper machines is towards higher running speeds. At the same time, the paper produced must have a higher and more even quality. In printing papers the main end-use properties and quality components are runnability, printability, and print quality. These coexistent requirements create new demands for the behaviour of the rolls under production conditions. High-quality printing paper grades are coated. In blade coating the thickness of the coating film on the paper surface is found to be heavily dependent on the run-out of the backing roll, which supports the paper web against the metering blade. The run-out tolerance of backing rolls at running speed has recently been 50 µm and should be substantially reduced in the future. The new tolerances can no longer be met by tightening the traditional roll manufacturing tolerances.

A new predictive 3D grinding method has been developed to improve roll behaviour in the paper production environment. It consists of a measuring system which can verify the rotational and geometrical errors of the roll at running speed and a 3D grinding system which controls the grinding process according to the information thus gained. In this study, the new method was applied to the backing rolls of a coating station. The experiments were carried out on a medium-weight coated (MWC) paper production line at a paper mill. The paper was analysed before and after the predictive 3D grinding.

The predictive 3D grinding reduced the machine direction (MD) ash variation by 65%. The ash variation correlates well with the coating variation. Because of the more even coating film, the MD gloss variation was reduced by 87%. Reduced gloss variation improves the print quality of LWC paper. The thickness variation from the backing rolls was reduced by 69%. More even paper thickness reduces excitations and therefore improves runnability in calendering, winding, and printing.

A new paradigm for roll grinding was set. The applications of the technology are not limited to high-speed paper machine rolls; the method can be applied to different kinds of rolls and nips. The method can compensate systematic errors causing nip force variation, such as uneven thermal expansion or the uneven bending stiffness of the rolls. With this method, it is also possible to implement rolls in applications, which have requirements too high to be met by traditional technology.

INTRODUCTION

In increasing the production capacity of paper machines, the predominant trend is towards higher running speeds rather than wider machines. It is envisaged that the trend will also continue in the future. As a result of higher running speeds, the rotational speeds of rolls and vibration problems have increased. The latest paper machines on the market are designed for a running speed of 2000 m/min. The paper-making process itself does not seem to be a limiting factor in increasing running speeds. For example, a pilot coating machine has a speed record of over 3100 m/min [1] and pilot paper machines have been running at over 2500 m/min. The speed difference between pilot and production machines is a result of the difficulties of making a wide machine instead of a narrow one. A wide machine has longer rolls, which means reduced natural frequency. In rolls with a steel body, the only effective way to increase the natural frequency is to increase the bending stiffness by increasing the diameter of the roll. Consequently, if the diameter is increased without the thickness of the cylindrical shell also being increased, the stiffness of the shell is reduced.

There are only a few studies concerning the correlation between roll geometry and variations in paper quality. Normally, the roll is considered to be an ideally round component in all circumstances. An exception was a study by Parker that mentioned roll roundness error as one source of excitation for calender barring problems [2]. This study was of the barring of newsprint by four-roll calender stacks. Parker also developed a theory that corrugation of certain wavelengths would grow spontaneously as a result of certain irregularities left after grinding. In addition, a curvature gauge was constructed, which proved that bar-marked rolls were corrugated. Later on, roll corrugation is mentioned as a source of excitation [3,4].

The first study of non-circular machining technology applied to compensating for the effects of structural errors in a roll was published in the early ’90s [5]. The aim of the study was to optimise the contact pressure in the nip of two cylinders, one of which had varying flexuraö stiffness. Non-circular turning of the roll reduced nip-pressure changes to one third, compared with the conventional machined roll. Another important step was the development of a four-point roundness measurement method and apparatus [6]. By means of this technology, it became possible for the first time to take effective roundness measurements of paper machine rolls. Later, this technology was applied to a device, which measures the dynamic behaviour of the high-speed rotating rolls [7, 8].

The main objective of coating is to increase the smoothness of paper considerably. Besides this, coating increases gloss, surface strength, and opacity. Coating also decreases ink absorption [9]. In printing, the smoothness of the gloss is important. This research is focused on improving coating film evenness in the coating process by reducing the errors deriving from backing rolls. Thus, in this research paper, 'quality' refers to the quality of coated paper. The main quality properties to be measured in coated paper are ash, basis weight (also called grammage), thickness, and gloss. Ash variation has a good correlation to coating variation, because, compared with the coating material, the base paper has a low ash content.

Research problem

The higher running speeds of coating machines have highlighted the importance of the dynamic behaviour of rolls and the runnability of the paper machine in general. At the same time, the paper produced must have a higher and more even quality. One of the most sensitive unit processes in paper production is paper coating. In blade coating, the thickness of the coating film on the paper surface is heavily dependent on the run-out of the backing rolls, which support the paper web during the process. The run-out tolerance of the backing rolls at running speed has recently been around 50 µm and, and in many cases, the run-out should be reduced to 30 µm. The new demands can no longer be met by tightening the roll manufacturing tolerances, which has traditionally been the solution to the problem. The accuracy of traditional manufacturing technology can no longer be increased at reasonable cost. The run-out in running speed is not created only by manufacturing tolerances; there are also problems with bearing accuracy and material homogeneity. Variations in material stiffness and heat expansion cause geometrical and rotational errors in the roll.

Machine direction (MD) variations have also been misinterpreted as cross-direction (CD) variation. Fu and Nuyan [10] proved that the aliasing effect of MD variability is present in CD profiles measured by scanning sensors. Originally, the aliasing problem is not truly a CD problem, but the CD controller acting on these false wavelengths introduces actual CD problems.

Problems with new high-speed machines are similar to those with the old machines, whose speed needs to be increased over the original design speed. The roll behaviour under production conditions is no longer satisfactory and major investment is needed to replace the old rolls with new and more accurate ones.

Could it be possible to increase the running speed of a paper machine and, at the same time, reduce variations in paper quality by using a non-conventional grinding method? This new predictive 3D grinding method should measure roll behaviour in a production environment and consider it in roll grinding. The geometry after non-circular grinding would be far from cylindrical but, in the production environment, the roll would achieve ideal geometry and therefore would work better than conventionally machined rolls.

Development of roll machining technology

The development of roll measurement and machining technology can be divided into three generations. The first-generation technology can measure and compensate for diameter variation of the roll in the axial direction. Typically, the error comes from the slideway straightness error of the machine tool.

The second-generation technology introduces roundness measurement and error compensation. With this technology, rolls can be machined very accurately to a desired, usually cylindrical, geometry, as shown in Figure 1. All the required measurements are taken in the roll grinding shop. The same kind of technology has been published in other fields, too. Advanced control technology for compensating spindle rotational errors [11] and for single-point diamond turning [12] have been presented. There are also novel applications in the manufacturing of optical components [13]. The technology can also be applied in machining pistons for combustion engines [14, 15].

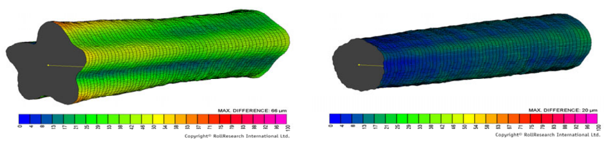

Fig. 1. Polymer-covered supercalender roll ground in the traditional way (left) and with the 3D grinding control technology.

The third-generation roll machining technology optimises the roll geometry to the production environment, so that the roll has the optimum geometry to carry out its specific process task. It means that we are no longer limited to ideal round and straight shapes during the grinding process. The rolls may be machined to oval and curved shapes or some other desired geometry. In the production environment these rolls achieve an ideal geometry and manage the process task better than rolls machined in the traditional way. The run-out behaviour at running speed is not affected by machining accuracy only but also by the rotational accuracy of the bearing assembly and the homogenity of the roll material.

METHODS AND MATERIALS

The experimental device consists of a measuring system (Figure 2), which can verify the rotational and geometrical errors of the roll at running speed, and a 3D grinding system (Figure 3), which controls the grinding process according to the measured information to within an accuracy of one micrometer.

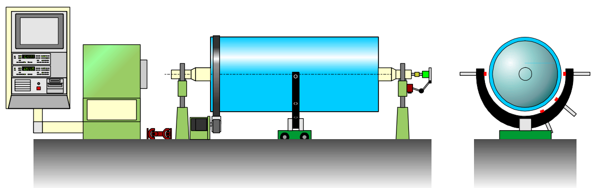

Fig. 2. Device for measuring the dynamic geometry of rotating cylinders [16].

Fig. 3. 3D grinding system provides the desired geometry to within an accuracy of one micrometer [17].

The new non-circular grinding method was applied to two similar backing rolls of a coating station. In this study, the results achieved with one roll are presented. The experiments were carried out on a medium-weight coated (MWC) paper production line at a paper mill. The roll behaviour and the paper quality variation were analysed before and after the predictive 3D grinding.

RESULTS AND DISCUSSION

Roll geometry and run-out

The roll roundness error at production speed in the middle cross-section was reduced from 55 to 13 micrometer (i.e. by 76%). At the ends, the roundness was already very good after traditional machining and the roll roundness improved by only 38% on average, from 20 to 12 and 14 to 9 micrometers.

The test roll exhibited remarkable asymmetric deformation as a function of running speed, as illustrated in Figure 4. This can be explained by the roll manufacturing process, in which the roll is welded together from two pieces of different lengths. Both parts have different mass distribution and stiffness, which leads to asymmetric deformation under high centrifugal forces. At the ends the stiffness of the end plates minimises the deformation. The residual error derives from the rotational error from the bearings, which is copied to roundness error during the grinding process.

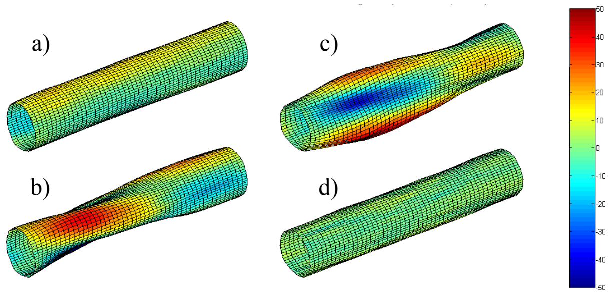

Fig. 4. Geometry of the test roll with traditional grinding at a low speed of 50 m/min (a) and at a production speed of 1120 m/min (b), and after predictive 3D grinding at low speed (c) and at production speed (d) respectively.

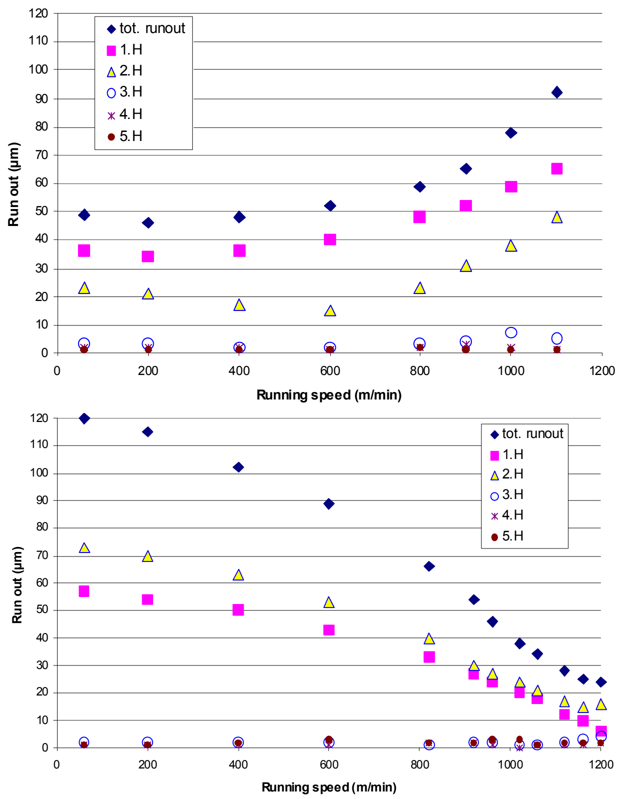

Fig. 5. Run-out with traditional grinding technology (above) and with predictive 3D grinding as a function of running speed. Total run-out and five harmonic components are shown.

With the 3D grinding technology the roundness of the rolls at running speed (Figure 4d) was significantly better compared to traditional grinding (Figure 4b). The result (Figure 4d) was even slightly better than the geometry at low speed after traditional grinding (Figure 4a).

The run-out is a sum of the out-of-roundness and rotational error motion of the roll axis. In flexible rotors eccentricity is normally the main component of run-out, as shown in Figure 5. Backing rolls with a large diameter and thin cylinder wall are an exception because of shell deformation as a function of running speed.

The test roll had a significant second harmonic, which derives from the oval-shaped deformed geometry at running speed. Predictive 3D grinding improved the roll run-out by 70%, from 92 to 28 micrometers, at production speed in the middle cross-section, as shown in Figure 5. At the ends, the run-out improved by 43%, from 37 to 14 and 33 to 25 micrometers respectively.

Ash variation in machine direction

The paper analysis shows a clear reduction in ash variation after predictive 3D grinding. A time domain analysis of a 100 m long sample shows that the peak-to-peak value has diminished from 3.9 g/m^2 to 1.5 g/m^2 (Figure 6).

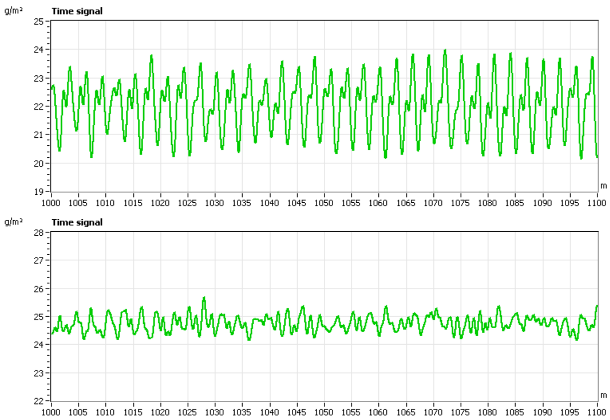

Fig. 6. Ash variation of the coated paper in the time domain in MD before (above) and after predictive 3D machining.

The paper grade was not exactly the same in both samples. The paper had more coating in the latter test (13.5 g/m^2 vs. 13 g/m^2 per side), where the backing rolls were ground with predictive 3D grinding. Normally, a greater thickness increases the thickness variation. Hence, the experiments would have most probably shown an even greater improvement with the same paper grade.

The correlation between ash and the run-out of the backing roll before and after predictive 3D machining is presented in Figure 7. In correlation analysis, each paper quantity is first analysed to separate the part caused by the backing roll in order to form a time domain signal which equals the perimeter of the roll. The ordered pairs of run-out and each paper quantity are then used for the calculations.

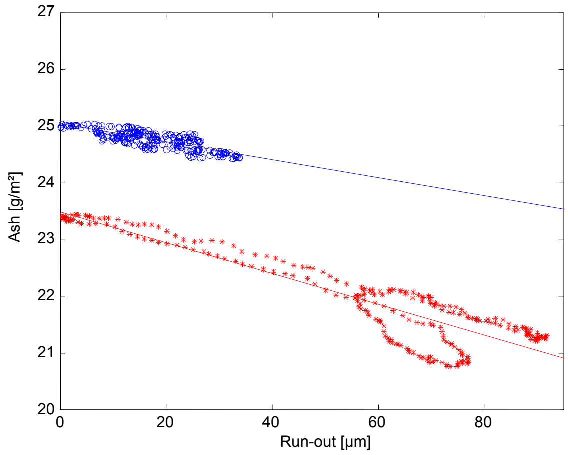

Fig. 7. The correlation between ash and the run-out of the backing roll before (stars) and after (circles) predictive 3D machining.

After traditional grinding the correlation between ash and run-out was very strong (0.92). After predictive 3D grinding, amplitudes were clearly reduced but the correlation was still strong (0.81).

Basis weight variation in machine direction

The paper analysis also shows a clear reduction in basis weight variation after predictive 3D grinding. A time-domain analysis of a 100 m long sample shows that the peak-to-peak value has diminished from 5.2 g/m^2 to 2.4 g/m^2 (Figure 8).

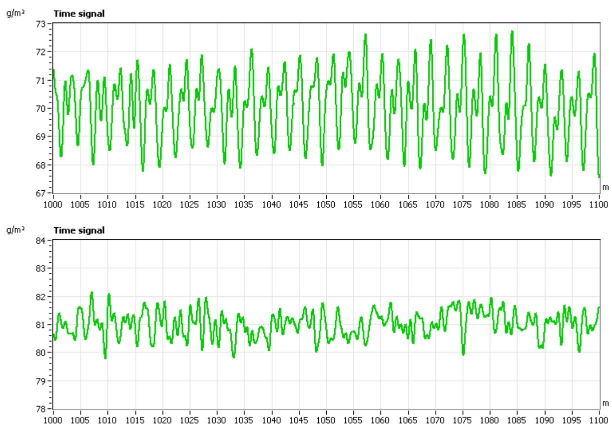

Fig. 8. Basis weight variation in the time domain of the coated paper in MD before (above) and after predictive 3D machining.

Thickness variation in machine direction

The paper analysis shows only a small reduction in thickness variation after predictive 3D grinding. A time-domain analysis of a 100 m long sample shows that the peak-to-peak value has diminished from 2.4 micrometers to 2.1 micrometers (Figure 9).

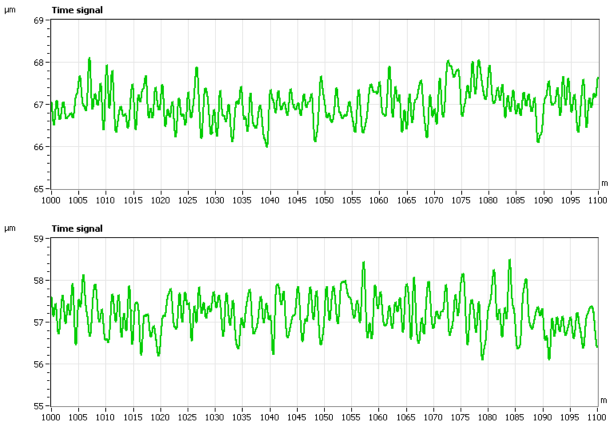

Fig. 9. Thickness variation of the coated paper in MD before (above) and after predictive 3D machining.

Gloss variation in machine direction

The paper analysis shows a clear reduction in gloss variation caused by the backing roll of the coating station after predictive 3D grinding. A time-domain analysis of a 100 m long sample shows that the peak-to-peak value has diminished from 7.9% to 2.9%.

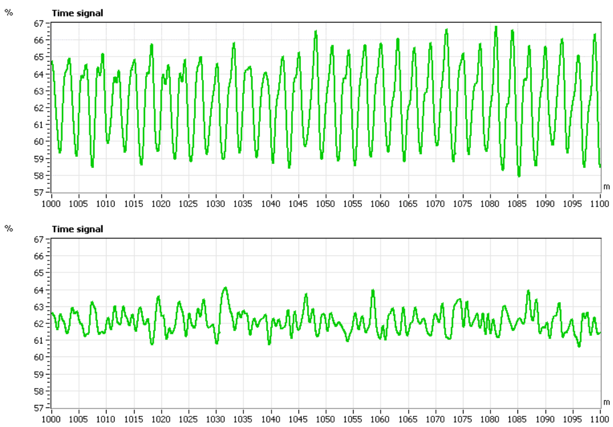

Fig. 10. Gloss variation of the coated paper in MD caused by the backing roll before (above) and after predictive 3D machining.

Table 1 presents variations in paper characteristics, synchronised to the rotating frequency and the harmonics of the backing roll. The results are presented after traditional grinding and after predictive 3D grinding. The values are based on spectral analysis of the total length of 4000 m long samples.

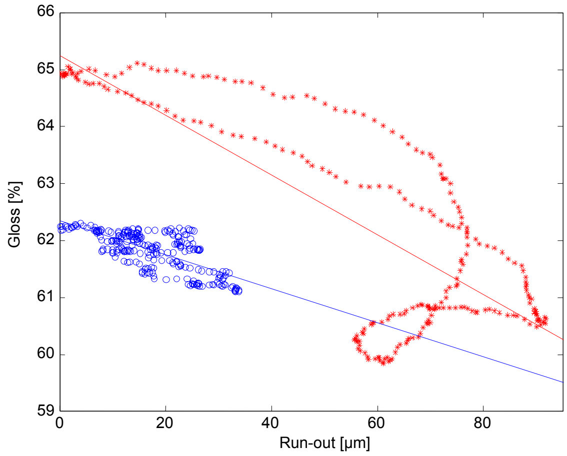

Fig. 11. The correlation between the gloss and run-out of the backing roll before (stars) and after (circles) predictive 3D machining.

After traditional grinding the correlation between gloss and run-out was substantial (0.79). After predictive 3D grinding amplitudes were clearly reduced but the correlation was still substantial (0.72).

Table 1. The influence of predictive 3D grinding of the backing roll on paper quality variation. The numbers are peak-to-peak values. Low pass filtering is 358 Hz.

	Traditional grinding	*3D grinding*	*Reduction %*
Ash (g/m^2)	2.0	0.7	65
Basis weight (g/m^2)	2.5	0.8	68
Thickness (µm)	1.3	0.4	69
Gloss 1 (%)	5.3	0.7	87

CONCLUSION

With predictive 3D grinding technology the roundness of the rolls was better at the running speed than with traditional grinding. Additionally, the run-out of the test rolls was reduced at the running speed. As a result, the process runnability was better, and grammage and gloss variations were reduced as well. Additionally, the study showed a clear correlation between roll run-out and paper quality variation.

The benefit of the results in paper coating is that no extra energy is needed to dry an uneven layer of wet coating material. If the process is limited by drying capacity, the more even coating layer makes an increase in speed possible. Paper with less coating material will no longer be overdried, which improves its strength properties. The main advantage, however, is the effect on printing quality.

The technology developed is cost-effective and can easily be applied to old machines on a paper production line where there is pressure to increase running speeds and paper quality. It has been proved that with this technology old rolls will run even better than the new rolls that are available. In new high-speed paper machines this technology provides a new tool to meet the tightening tolerances of rotational and geometric accuracy.

The method can be applied to different kinds of rolls to compensate for systematic errors such as uneven thermal expansion and uneven bending stiffness, which cause, for example, nip force variations.

REFERENCES

1. Oinonen, H., (1998). Järvenpään teknologiakeskus uusittiin perinpohjin: Päällystysnopeus ei enää ole tuotannon lisäyksen pullonkaula. Paperi ja Puu. Vol. 80. No 8. pp. 576-580.
2. Parker, J.R. (1965). Corrugation of calender rolls and the barring of newsprint. Paper Technology, Vol. 6, No.1 pp. 33-41(T1-T9).
3. Tervonen, M. (1984). Barring of newsprint in the machine calender – The vibration models of the calendar. Licentiate's thesis, University of Oulu, Department of Mechanical Engineering. Oulu. 89 p.
4. Nevaranta, J. (1984). Barring of newsprint in the machine calender – The causes and elimination. Licentiate's thesis, University of Oulu, Department of Mechanical Engineering. Oulu. 53 p.
5. Kuosmanen, P. (1992). Optimization of the contact pressure in the nip of two non-ideal cylinders. Licentiate's thesis, Helsinki University of Technology. Espoo. 77 p.
6. Kuosmanen, P. & Väänänen P. (1996). New Highly Advanced Roll Measurement Technology. Proceedings of 5th international conference on new available techniques. The word pulp and paper week June 4-7 1996; Stockholm, Sweden. pp. 1056-1063.
7. Pullinen, J., et al. (1997). Influence of reconditioning on the dynamic behavior of the backing roll. Helsinki University of Technology, Laboratory of Machine Design, Publication C 286. ISBN 951-22-3741-5. Otaniemi 1997. 74 p.
8. Juhanko J. (1999). Dynamic behaviour of a paper machine roll. Licentiate's thesis, Helsinki University of Technology. Espoo, 82 p.
9. Lehtinen, E. (2000). Introduction to pigment coating of paper. Book 11: Pigment coating and surface sizing of paper, ed. E. Lehtinen. In: Papermaking Science and technology, ed. Gullichen, J. and Paulapuro, H. Fapet Oy, Helsinki 2000, 810 p, ISBN 952-5216-11-X.
10. Fu, C., Nuyan, S. (2002). Mill experinces on Cross-Machine Direction Troubleshooting, Proceedings of Tappi Technology Summit 2002, Atlanta GA. United States. 3-7 March, 2002.
11. Kim, K.H., (1983). 'Forecasting compensatory control of roundness in cylindrical grinding' Ph. D. Thesis. University of Wisconsin-Madison, Wisconsin, USA, 1983. 148 p.
12. Uda, Y., et. al. (1996). 'In-process measurement and workpiece-referred form accuracy control system (WORFAC): application to cylindrical turning using an ordinary lathe' Precision Engineering 18: 50-55, 1996.
13. Weck, M., Pyra, M., Özmeral, H. 'Non-Rotational-Symmetric Optics and their Applications' Proceedings of the 3rd International Conference on Ultraprecision in Manufacturing Engineering. Aachen, Germany, 2-6 May 1994.
14. Higuchi, T., Yamaguchi, T., Tanaka, M. (1996). 'Development of a high speed non-circular machining NC-lathe for cutting a piston-head of a reciprocating engine by use of a new servomechanism actuated by electromagnetic attractive force' Journal of the Japan Society of Precision Engineering. March 1996; 62(3): 453-7.
15. Schnurr, B., (1998). 'Electrodynamisches Antriebsystem zur Unrundbearbeitung' Doctor Thesis. Universität Stuttgart. 176 p.
16. Hybrid DynaTest. RollResearch International Ltd. Http://www.rollresearch.fi.
17. Hybrid GrindControl 3D. RollResearch International Ltd. Http://www.rollresearch.fi.