FEA Simulation & Prediction of Cylinder Bore Distortion in Diesel Engines

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***Abstract*— IC engine industries these days is in the direction of a shorter product improvement cycle and quicker time to marketplace with multiplied emphasis on up the front evaluation to design, expand and optimize a dependable and sturdy product. Today, the calculation of balance of important additives like e. g. , the cylinder head and the cylinder block Cylinder bore distortion in IC engines has been diagnosed as a motive for gasoline and oil consumption, consequently it impacts performance and emissions. The bore distortion of the cylinder turned into obtained, and its orders calculated via Fourier series.**

The ring sealing potential withinside the distorted bore cylinder analyzed.

Keywords—Cylinder bore distortion, Surface Distortion, FEA

I. INTRODUCTION

The mechanical parts interposed between the piston and the liner to provide air tightness, oil distribution, and oil scraping are known as piston rings. However, their tightness isn't ideal, and blow-by gas occurs when some of the intake gas mixture escapes into the crankcase.

Furthermore, during the exhaust stroke, some trapped Gas may return to the combustion chamber and be discharged as unburned hydrocarbons, a phenomenon known as blow-back. Heat transmission, oil control and distribution, and piston support are some of the responsibilities. They make touch with the piston grooves on one inner and lateral side, and the cylinder liner on the other. Tolerances, ring cross-section, and motion dynamics all have a big impact on the contact with the piston. The lateral force exerted by the ring and the deformation of the cylinder liner effect the contact on the outer side. High forces, pressures, and temperatures are applied to the cylinder bore. Furthermore, heat dilatation produces cylinder block expansions and compressions, which results in axial cylinder distortion and the addition of distortion orders.

Bore Distortion means deviation from ideal circular shape (roundness) or bore out of roundness. Initially it is understood that manufacturing tolerances can cause the bore to deviate from ideal condition. The main types of distortions that occur in an engine are

1. Cylinder liner bore distortion.
2. Main bearing bore distortion.
3. Connecting rod bore distortion.

Amongst which cylinder liner bore distortion is major as compared to the others. Even with the best of intentions and preparation, an unavoidable degree of cylinder bore distortion is likely to occur under dynamic stress (heat and pressure). The challenge is to understand how these changes take place and to establish procedures that will attempt to minimize these changes.

II. NEED OF STUDY

Air-cooled/water cooled Diesel/ petrol/gas engine, for instance, is commonly used in heavy-duty transport fleets applications due to their high performance, efficiency, and low fuel consumption. But when bore deformation occurs the following problem may arise:

A. Blowby

Blow by is the loss of combustion gases from the combustion chamber, past the piston and into the crankcase. This is undesirable as the gas takes energy with it, reducing the pressure on the piston face and reducing the power output of the engine..

B. Oil consumption:

If the piston (or piston rings) were in direct contact with the cylinder wall then the combustion chamber would be sealed off perfectly, but it would require a huge force to move the piston against the friction generated.

C. Engine Seize:

Due to bore distortion in the engine temperature rise occur which causes engine seize problem. So, these are some major problems occurs due to bore distortion.so to reduce these problems it is necessary to find out the bore distortion in initial stages.

D. Design Process:

Bore distortion assessment is required to avoid many issues as mentioned above and optimum performance of engine. It has very complex study to carried out. Also, more possibility to errors in it. In this project, design process can be optimized and additional terms to make good correlation and it checks with experimental data can be done. And it is the basic motivation of this project.

III. OBJECTIVE & SCOPE

A. The objective of this project is to do simulation for bore distortion and make experimental validation on single Cylinder engine with different conditions. To Correlate experimental data and simulation data, development of analytical algorithm based on Harmonic/Modal Coefficient and Fast Fourier Transforms to evaluate this study. Bore distortion is the one of the critical studies in structural solid mechanics to achieve good correlation to experimental

a. To Perform study on Causes for Bore distortion issue

b. To study of different techniques to reduce Distortion in bore faces

c. To study of different techniques to do experimental validation of bore Distortion and its measurement

d. To study a simulation methods and engine boundary condition to build mathematical problem

e. To study different kind of analytical/mathematical relations to develop an algorithm which can help to get optimum results and can be show good correlation to experimental data

So, this project has multiple kind of assumptions and factors need to be study to develop a process algorithm and validation. Using Ansys Software this study will be conducted.

IV. ANALYTICS OF CYLINDER BORE DISTORTION

A. Cylinder Bore Distortion

The distortion of the cylinder bore and its effect on the piston-ring-cylinder coupling, has been object of investigation from several authors.

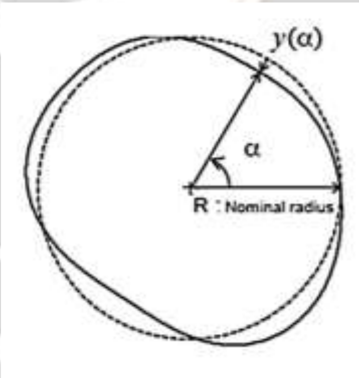


Fig. 3.6 Distortion of the bore

The bore distortion of a transversal section in a cylinder liner is given in Fig. 6, and can be modeled by means of Fourier series according to Eq. (7):

$$y_\alpha = A_0 + \sum_{k=1}^{n} A_k \sin(k_\alpha + \varphi_k)$$

Where:
A = position around the circumference,
Ak and φk=magnitude and phase of the kth distortion order.

The real deformed bore shape is the combination of different orders.
Order 0 corresponds to a uniform expansion of the circumference near the top dead center, due to high temperature and pressure in the combustion chamber.
Order 1 distortion represents a rigid shift of the cylinder axis with respect to the nominal axis. This shift is the result of the deformation between top and bottom part of adjacent cylinders.

Order 2 distortion shows an elliptical deformation shape and arises due to the expansion of the cylinder top part and compression of the cylinder bottom part.
Order 3 distortion shows a three-lobe deformation (n=3) and is highly influenced by thermal loads.
Order 4 distortion (n=4) shows a typical clover leaf deformed shape and is highly influenced by the tightening forces exerted by the head bolts on the cylinder block. In general, order zero and order one have larger magnitudes of distortion than orders two to four. Generally speaking, orders ⩾ 4 show low magnitude on the distortion of the cylinder and thus are not analyzed. Figure 7 shows the first five distortion orders.

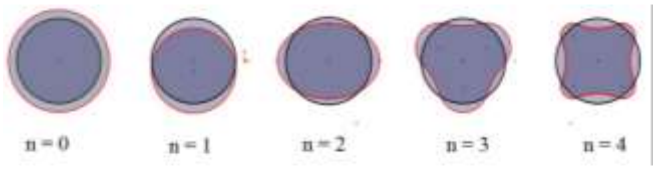


Fig. 3.7 Bore distortion Orders

B. Harmonic Distortions

This kind of distortion causes a regular, sinusoidal deformation in the cylinder, which can be derived mathematically from measurements of the surface of the cylinder. The 'harmonic' refers to the building up of the real shape from a combination of many sinusoidal waves of different orders (see below). A first order distortion appears as an offset of the whole section from the main axis, a second order appears as an 'ovaling' of the section, a third as a three lobed deformation, a fourth as four lobes, and so on. Theoretically an infinite number of orders combine to make up the final shape, the magnitudes and directions of these orders are calculated by using the Fourier series and applying it to measurements of the bore.

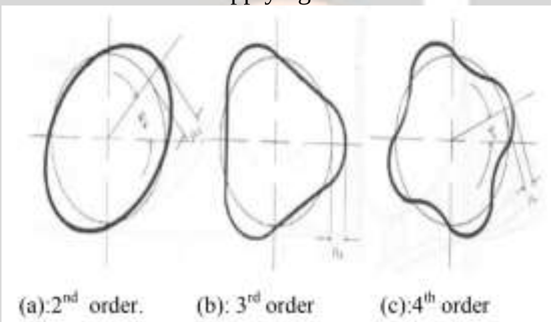


Fig.3.8 Harmonic order shape plots

C. Causes Of Distortions

The cylinder block, as cast, has only a rough shape with tolerances of around 0.5-1mm, but machining of the surfaces aims to give as perfect a cylinder as possible (first with a rough drilling and then with a polishing/honing process to reach the final tolerances in the region of tens of microns). Even after this there will be a small, but measurable deviation from the ideal shape, but the design of the piston rings allows them to conform easily to these small distortions.

D. Bolt Loads

Cylinder heads, bearing shells and bearing carriers all require bolting to the cylinder block and the bolts used will unavoidably deform the block. Heads are the primary cause of fourth order distortions, bearing carriers cause second order and the unsymmetrical supports on the outside bore of blocks cause third order distortions. As expected, the higher the bolt loads, the greater the distortion, but placement of the bolt threads, and the depths to which they sink can affect distortion to a great extent. With cylinder liners, supports, cooling jackets, head gaskets, external mountings and other considerations, the design of blocks to minimize distortion is a complex subject, and is beyond the scope of this report –which aims only to find simple method of measuring, quantifying and comparing distortions.

E. Temperature

At present the most accurate measures of the shape of the bore can only be made with the engine disassembled as the harsh conditions during combustion give rise to serious (but not unsurpassable) problems when trying to measure the bore. As a result, most distortions are measured cold (25°C). Since the temperature gradient during operation can range from below zero °C outside (at start-up) to over 2000°C inside the bore, deformation of the bore by thermal expansion is common (with the greatest expansion occurring, naturally, towards the combustion face of the block).

F. Bolting Concept

The connection between block and head can be done either conventionally or by the through-bolt technique. In case of conventional bolting, the cylinder head and grey iron bearings are bolted directly to the block resulting in high stresses in the vicinity of the thread and the bolt head. This bolting concept reaches its limits in case of high loaded direct injection diesel engines. In order to prevent high tensile stresses in the engine block, the main bearings and the cylinder head can be connected directly by long bolts which penetrate the whole block and head, thus setting them under compressive stress only (through-bolt concept).

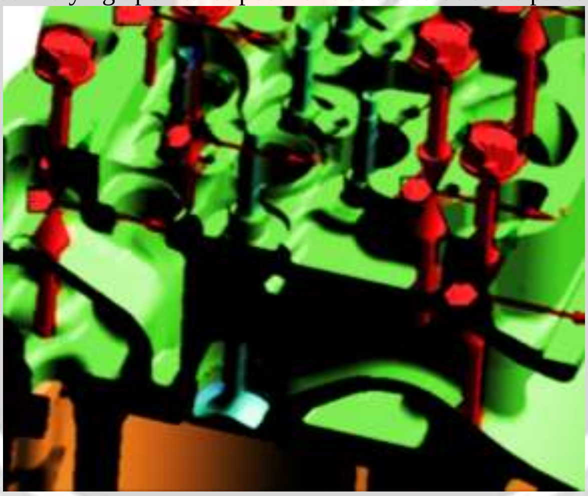
V. FEM APPROACH

It is not always possible to obtain the exact analytical solution at any location in the body, especially for those elements having complex shapes or geometries. Always matters are the boundary conditions and material properties. In such cases, the analytical solution that satisfies the governing equation or gives extreme values for the governing functional is difficult to obtain. Hence for most of the practical problems, the engineer's resort to numerical methods like the finite element method to obtain approximate but most

A. PROBLEMS, MATHEMATICAL MODELS, AND THE FINITE ELEMENT SOLUTION:

The actual issue commonly includes a real construction or primary part exposed to specific burdens. The glorification of the actual issue to a numerical model requires specific suspicions that together lead to differential conditions overseeing the numerical model. The limited component examination settles this numerical model. Since the limited component arrangement strategy is a mathematical system, getting to the arrangement accuracy is vital. On the off chance that the exactness rules are not met, the mathematical arrangement should be rehashed with refined arrangement boundaries (like better networks) until an adequate precision is reached. The limited component arrangement will settle just the chose numerical model and that all presumptions in this model will be reflected in the anticipated reaction.

Thus, the decision of a suitable numerical model is pivotal and totally decides the understanding into the real actual issue that we get by the examination. When the numerical model has been settled precisely and the outcomes have been deciphered, we might well choose to consider next a refined numerical model to build our understanding into the reaction of the actual issue. Moreover, an adjustment of the actual issue might be important, and this thus will likewise prompt extra numerical models and limited component arrangements. The key stage in designing examination is consequently picking proper numerical models. These models will obviously be chosen relying upon what peculiarities are to be anticipated.



B. ADVANTAGES AND LIMITATIONS OF FEA:

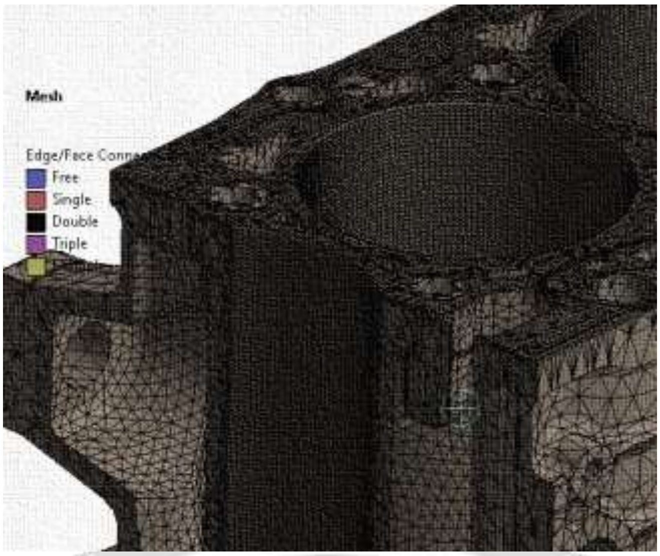
Planning the analysis is arguably the most important part of any analysis, as it helps ensure the success of the simulation. Oddly enough, it is usually the one analyst's leave out. The purpose of an FE analysis is to model the behavior of a structure under a system of loads. In order to do so, all influencing factors must be considered and determined, whether their effects are considerable or negligible on the result.

The degree of accuracy to which any system can be modeled is very much dependent on the level of planning that has been carried out. FEA is an approximate way of simulating the system behavior. But the results can be quite close to actual testing values. FEA can never replace actual physical testing all the time. This is due to the fact, the information required for FEA simulations, like material properties emanates from physical testing. FEA results by themselves can never be taken as complete solution. Usually at least one prototype testing is necessary before the design guided/validated through FEA can be certified. But when effectively used FEA can predict the results/behavior quite close to reality and can reduce the design lead times as well as the number of prototypes to be tested.

C. MESH REQUIREMENTS:

The Finite Element Method (FEM) has certain requirements on a mesh:

Usually there are certain parameters that determine the quality of the results. The Engineer has to ensure that these parameters are maintained to the minimum required levels in the FE model for obtaining good results.



D. NON-LINEAR STRUCTURAL ANALYSIS:

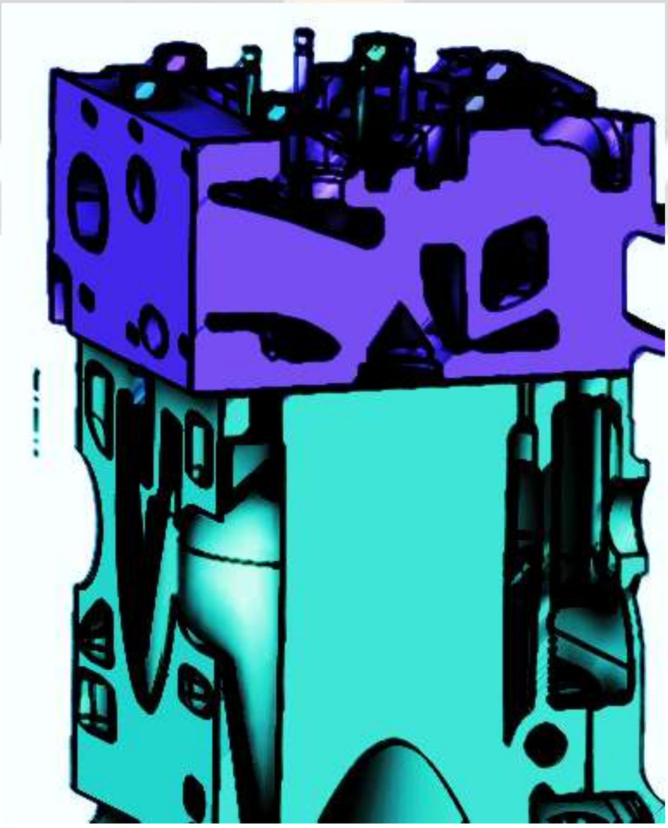
When structure response (deformation, stress & strain) is linearly proportional to magnitude of load then the analysis of such a structure is known as linear analysis.

When the load to response relationship is not linearly proportional, then the analysis falls under nonlinear analysis. For example, when a compact structure made of stiff metal is subjected to a load with relatively lower in magnitude as compared to strength of material, the deformation in structure will be linearly proportional to the load and the structure is known to have subjected to linear static deformation. But most of the time either material behavior will not be linear in the operating condition or geometry of the structure itself keep it from responding linearly. Due to cost or weight advantage of nonmetal (polymers, woods, composites etc.) Over metals, nonmetals are replacing metals for variety of applications, which have nonlinear load to response characteristics, even under mild loading conditions.:

Material nonlinearity (Strains beyond the elastic limit (plasticity))

Geometric nonlinearity (Large deflections, such as with a loaded fishing rod)

Boundary nonlinearity Contact between two bodies.



E. MATERIAL PROPERTIES:

Material property must frequently be approximated in FEM. Indeed of course there is an accepted degree of variation in the young's modulus of even the most standard of engineering material. In above problem there are two non-linearities takes places, material and contact.
In material non linearities there two types again. 1) Plastic non-linearity 2) Intrinsic non-linearity.

F. CONTACTS:

Contact needs to be defined wherever necessary. It allows proper transmission of forces. Contact occurs when the element surface penetrates one of the target segment elements on a specified target surface. If more than one target surface will contact the same boundary of solid elements, you must define several contact elements that share the same geometry but relate to separate targets (targets with different real constant numbers), or you must combine the two target surfaces into one (both having the same real constant number).

G. SIMULATION

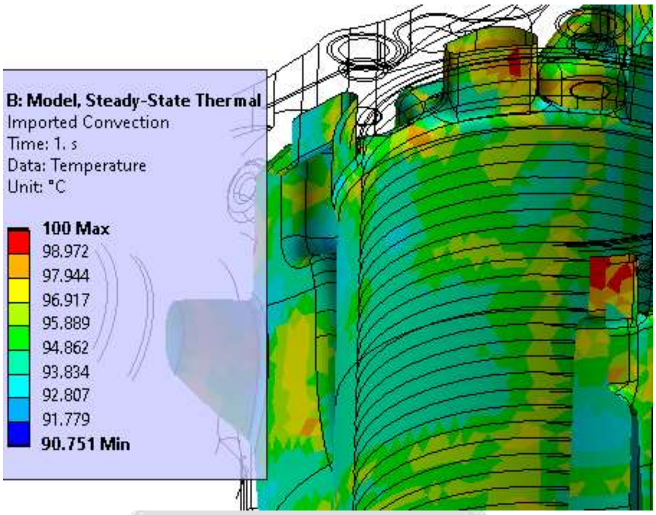
In the current work, the issue was stretched out with the impact of the drag contortion on the ring pack execution. To explore the impact of the drag bending on the fixing limit of the ring pack, a bunch of recreations were performed on the test motor. The re-enactments were performed thinking about at first the straight drag (ostensible width), consequently was presented every contortion request as it happened independently, and toward the end the ostensible misshaped bore.

The consequence of the reproductions when the chamber bore is disfigured by request zero contortion design. Request zero bending makes the chamber liner to grow close to the top on target and increments straightly the drag range as seen. In these circumstances, the pressure rings will likewise grow and follow the new drag sweep, expanding their holes and permitting bigger ways for the gas to stream. This reality is affirmed by the strain diagram, where the subsequent land pressure came about to be expanded, and at around 150-degree wrench point after ignition, came to and conquer the top land pressure.

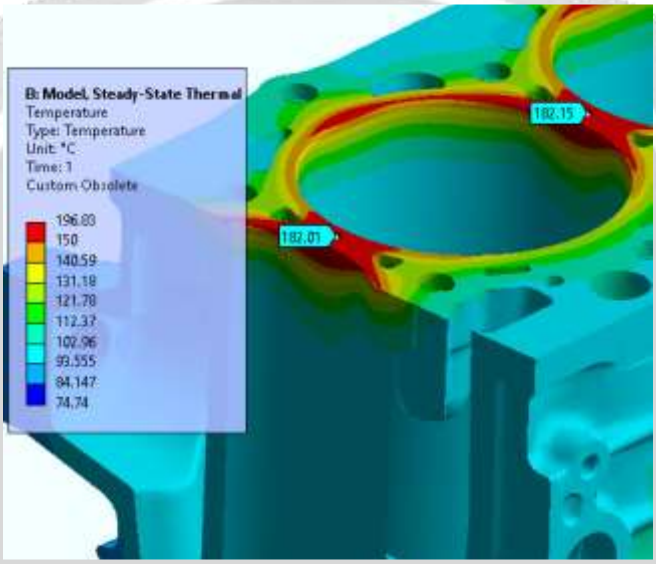
As per the strain chart, the subsequent land pressure got over the top land tension at roughly 120 wrench point degree, likewise none of the rings encountered an outspread breakdown for this situation. The consequences of the reproductions when the chamber bore is disfigured by request one bending design. Request one bending addresses an unbending movement of the chamber hub as for the chamber block pivot. For this situation, the ring elements, entomb ring tensions and ring/liner leeway are practically similar to the non-mutilated case, with exemption for the pinnacle pressure values in the terrains. The justification for this similitude is connected to the way that this request addresses a more direct mutilation and less spiral one. For this situation, the cylinder and its rings can follow very well the state of the chamber, guaranteeing a high comparability to the liner.

As indicated by the subsequent ring goes through a spiral breakdown. This conduct is inclined toward by the missing movement of the top ring (lift = 0), which impedes the retrogressive gas stream to the top land. Because of this explanation, the high-pressure gas pushes the second ring inwards and opens an immediate way to stream downwards. Both for this situation and in the non-twisted bore, the outspread breakdown happened while the ring is situated at the highest point of the depression. The subsequent request addresses a curved shape contortion, brought about by the extension of the chamber block upper part and the pressure of the lower part. For this situation, the way of behaving of the framework will be not additionally clarified in light of its comparability for the request one case, exemption made for a marginally higher second land pressure. The low mutilation greatness for this request, along with the great limit of the ring pack to adjust over it, has made it to perform like the request one bending. This mutilation will make the rings to adjust in a superior manner with the liner, in the event that the twisting extent is equivalent or lower to the base oil film thickness, and simultaneously it will cause a decrease of the ring holes.

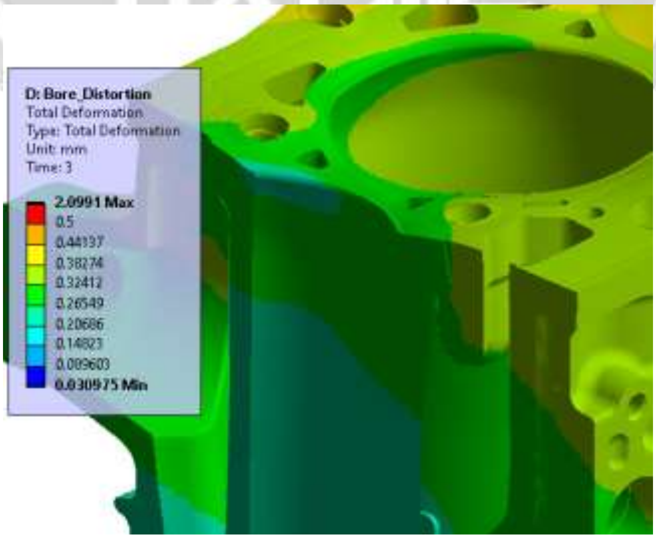
Because of this conduct the top ring could really impede the gas stream, as affirmed by the tension bends, which were of extremely low qualities during the whole cycle. Just when the top ring lifted, the subsequent land tension could rise and cross the top land pressure, keeping a higher incentive for a short measure of time. It is feasible to guarantee that the top ring has lifted exclusively because of the dormancy force, equivalent to the second and third rings, which lifted in correspondence to the difference in the stroke. Nobody of the rings experienced spiral breakdown. As per results, the top ring stays stable in its lower groove flank, yet the second and third ring experienced ceaseless variety of their situation in the scores. This proof shows that no matter what an ideally found top ring ready, a few gas can stream downwards. This conduct is affirmed through the strain chart, where the subsequent land pressure shows a rising pattern until it happens a spiral breakdown of the subsequent ring. After this point, the strain bend in the subsequent land displays a sharp fall, while the tension of the third land a slight ascent.



CFD Analysis of cooling jackets



Static Thermal Analysis of Cylinder Block



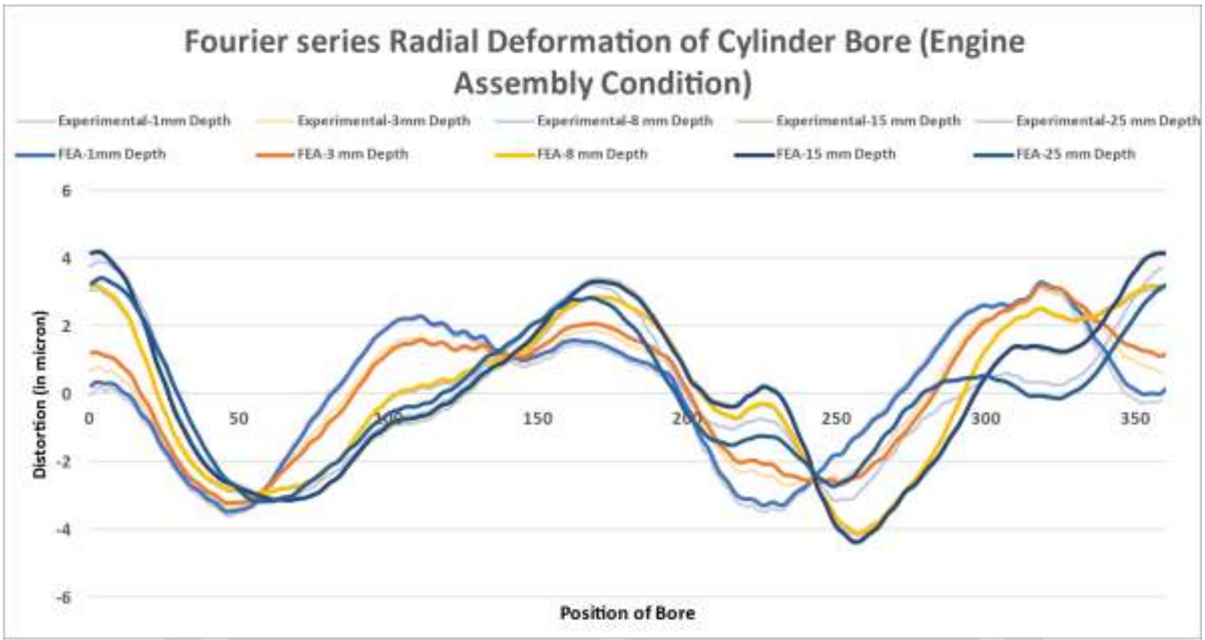
Deformations for Cylinder Bore

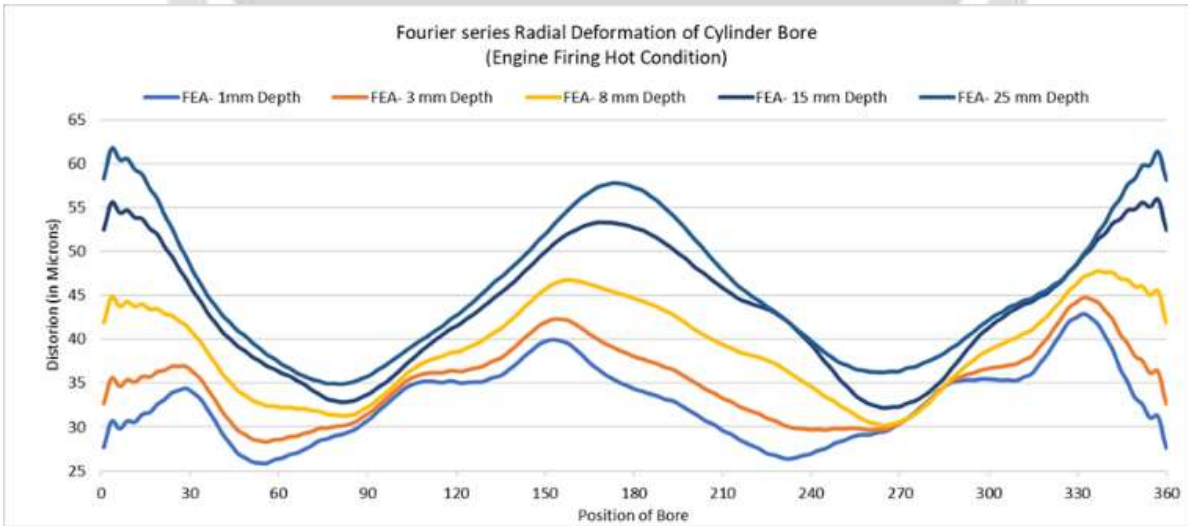
VI. EXPERIMENTAL CORRELATION AND PREDICTION OF DISTORTION

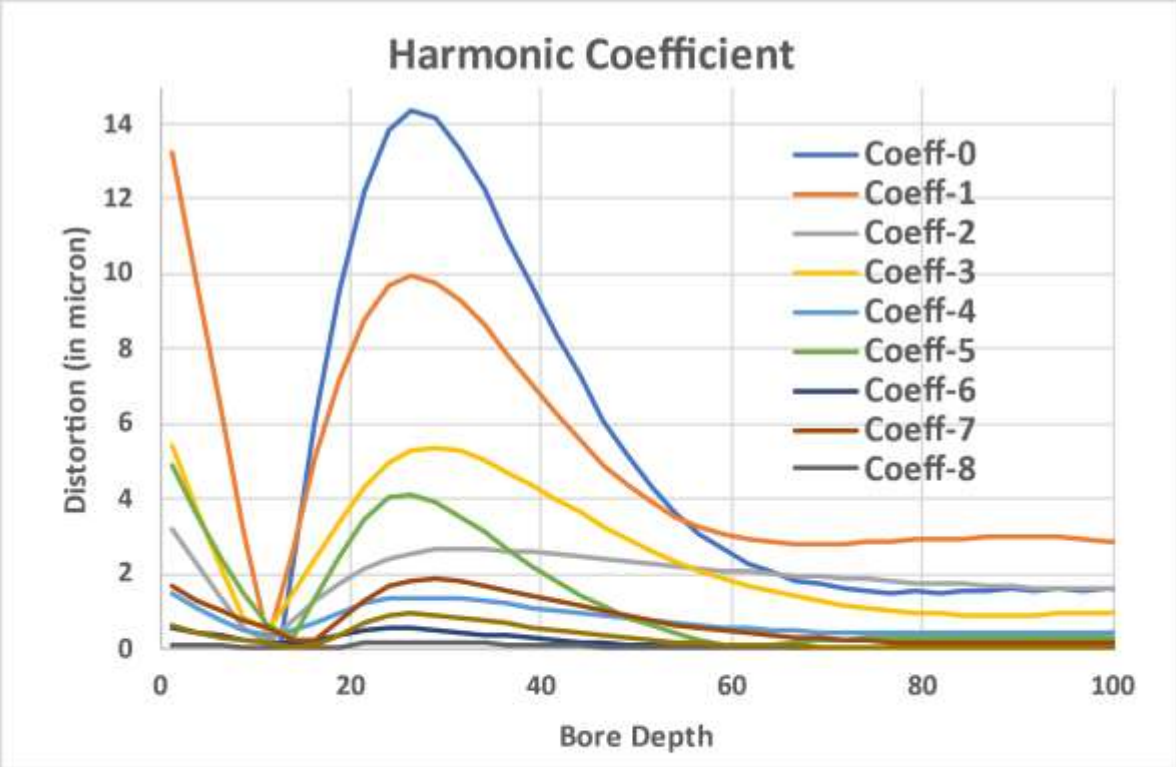
The strategy introduced in this original copy has been executed, tried and contrasted and the other business and in-house programming. Exceptionally close outcomes are produced by the proposed system contrasted and the other programming. For the drag mutilation examination, while some business programming can't process the best fit chamber accurately on account of genuinely enormous pivot of the chamber hub, the proposed strategy can deal with it accurately.

Some valve seat bending and chamber bore contortion results created by utilizing the proposed philosophy are introduced. Figure 6 shows the in-plane twists of admission valve seats of the right-hand side chamber top of a motor. The roundness, the extents of the second, third and fourth request Fourier coefficients for assessing the chamber bore twisting of a motor are displayed in Figures

The proposed technique is not difficult to utilize. The contributions to the code are the lattice data and the result documents for relocations of gage line hubs and hubs on the inward surface of the chamber exhausts. A similar cross section document for reproduction with next to no altering can be utilized as the contribution to the code. The code will track down the required data from the info records and do the post-handling without client intercession. Along these lines, normal blunders in information move by hand are stayed away from. For most post-handling, it requires somewhere around 10 seconds to finish. Assuming the business programming is utilized for this reason, individual best fit calculations must be thought of one as by one, and the best fit results must be recorded the hard way. It might require hours for the post-handling. Hence, a ton of time and cost can be saved by utilizing the proposed strategy.







VII. Conclusion

An object-oriented framework for post-processing the distortion is proposed in this manuscript. Algorithms for finding the best fit plane, the best fit line, the best fit circle and the best fit cylinder are presented. These algorithms are needed in assessing the distortions and misalignments in engine components. Object-oriented implementation in Ansys Classic programming language for finding the best fit geometries and assessing the distortions and misalignments is outlined. Numerical examples are given to demonstrate the efficiency and correctness of the proposed technique.
Compared with the post-processing method by using the commercial software, the proposed technique can substantially save time and cost in assessing distortions and misalignments in engine components.

The results, which proved to be in very good correlation with the literature by considering the following important outcome emerged from the discussions:

• Bore distortion is a very important factor because it affects the sealing capability in different manner for each order.

• Ring axial or radial dynamics are affected from the distortion orders; however, this motion not always explains the amount of gas flowed in the regions.

• The highest values of blow by were recorded in the cases where there was no radial collapse.

• The comparison between the blow by for the non-distorted bore (desired result) and the blow by for the distorted bore (real result), can be used as a benchmark for further improvements.

• Order zero distortion considerably reduces the ring sealing capability. The high gas pressure and temperature can't be avoided, but the cylinder block should be designed to reduce the magnitude of distortion for this order.

• Orders one and two are roughly caused from the same factors, in addition, their results are both like the non-distorted bore shape. Hence, reducing these factors could double the benefits.

• Orders three and four must be studied more carefully. Although they show a lower distortion magnitude, their blow by values is relatively high.

• Experimental Validation: All results can be plotted in the excel sheet. In comparison of perfect bore with the distorted bore and FEM results will takes place. As discussed in earlier chapter distortion were measured at 10 planes. Readings can be measured at different levels.

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