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DEMONSTRATION OF TURBOCHARGERS BALANCING PROTOTYPE MACHINE FUNCTIONALITY IN RELEVANT OPERATING CONDITIONS

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Abstract: *A turbocharger must be measured on a VSR (vibration sorting rig) and balanced in order to obtain a durable product who will withstand the service life specified by manufacturer (generally 1- or 2-years warranty depends by manufacturer or type of turbocharger). Unbalance of turbocharger rotor creates always vibrations which could be very destructive for the bearing. The purpose of experiment is to prove balancing is possible without any prediction algorithm still with good results. For the demonstration of manual balancing a prototype machine was built and 10 turbochargers were used.*

Key words: *turbocharger, balancing, Gauge R&R calibration, high speed balancing machines.*

1. INTRODUCTION

For high volumes, the production tolerances used to manufacture the rotors are adjusted to an optimal value because it's more economical to produce parts that are not perfect and then balance them. Causes of irregularity during the production of different rotors are machining error, cumulative assembly tolerances, distortions due to heat treatment, blow holes or inclusions in castings, and material non-homogeneity. [1]

Irregularities in the manufactured parts produce vibration which are proportional to the rotating speed of the rotor squared. In its simplest form, vibration can be assimilated with an oscillating motion or with a repetitive motion of an object around its equilibrium position. The equilibrium position is considered the position in which the force acting on the object is zero.[2-3]

Vibration is undesirable in rotors, especially in high speed ones where it can be very destructive and significantly reduce the product life span and create unwanted sound. [1, 3-5]

The unbalance of a rotor can be static or dynamic, the difference is the number of axial planes were the unbalance appears.

There are three basic methods for balancing: adding mass; removing mass and displacing mass. [5-6]

Vibration measurement has evolved from the early requirements of the aerospace industry.

Any turbocharger balancing machine has 3 important elements:

- VSR tooling – which is important to reduce the influence of external vibration over CHRA, this also plays a key role in securing and supporting the test part;
- Air supply and control system;
- Data acquisition system which consists of speed sensor, vibration sensor; data processing module and software;

The air feeding system needs to have a good stability and control in term of pressure and flow. [6-7]

The software requirements are:

- to display the values in real time and to offer good control;
- to have a window where to show the acceleration values vs. speed

In order to have a good sensitivity the accelerometer position must be as closest as possible to the source of vibration, CHRA in our case. [5-7]

Prices for the automatic balancing machine are very high and are not suitable for small batches or for the after-market segment. Due to the above mentioned reason a prototype manual balancing machine was developed which can achieve a good balancing capability at a much lower price.

The purpose of the study is to demonstrate the functionality of the turbochargers balancing prototype machine in industrial conditions.

2. EQUIPMENT AND METHODS

In Fig. 1 can se be seen the prototype tooling which consists out of (from right to left) a spinning part, a fixture for CHRA and a compressor cup. In fig. 2 can be seen the section of tooling.

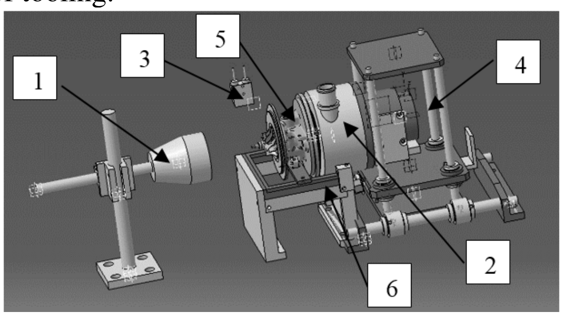

Fig. 1. The 3D scheme of tooling
1 – compressor cup, 2 – Tooling nozzle, 3 – Optical sensor, 4 – Tooling base and fixture, 5 – CHRA
6 – Testing part fixture

The electrical/electronical components of balancing machine:

1. Accelerometer: Model 355B03 - Ring-style, high sensitivity, ceramic shear ICP® accel., 100 mV/g, 1 to 10k
2. Optical sensor: Keyence Serie IL co-focal with laser diode and fiber optics
3. Optical signal amplifier: Keyence FS-N41 using Ultra-High-Speed settings, sensitivity 4500, light-on.
4. National Instruments MyRio 1900 student version
5. Pilot electro valve CKD EV2500-008-c11 with pressure control +0.05Mpa
6. Piloted valve CKD 2303-8C
7. Oil pump: JBM-53566 12V; 2 L/min
8. Software built in Labview 2014

For oil feeding system was used an oil tank, an electrical tension variator, an electrical pump all started and stopped manually, independently from data acquisition system.

For data acquisition and control was used a MyRio student version from National Instruments, together with an interface PCB for specific connectors of electro valve, accelerometer and optical sensor.

The software was built in LabView version 2014, 32 bits. In fig. 2 can be seen the programming blocks layout of machine software.

Software modules and drivers used:

- NI-MyRio drivers
- LabView 2014, 32 bits
- NI LabVIEW Development System
- NI LabVIEW Real-Time Module
- NI LabVIEW FPGA
- LabVIEW 2014 Control Design and Simulation Module
- LabVIEW MathScript RT Module
- LabVIEW Robotics Module for LabRIO
- Compilation Tools for Vivado
- VI Package Manager
- Vision Acquisition Software
- Vision Development Module LabVIEW MyRio Toolkit
- NI MAX measurement and automation explorer

The fig.2 are the resulted interface for settings and cycle control and measurement.

The software interface has a START (RUN) button and an Emergency STOP. Values displayed real time by software: acceleration (g) vs. speed (Hz). With other words, values are displayed during the center housing rotating assembly acceleration cycle, not after that. Also, the acceleration is synchronously measured with rotation speed.

The settings interface (fig. 2.) help to adjust the minimum opening of electro valve measurement range, electro valve opening steps, manual opening at a specified voltage, also a window for the optical signal.

In this interface is possible to make test runs, can adjust the opening steps of pilot valve, can monitor the voltage on valve, it helps to adjust the optical sensor and monitor the G level.

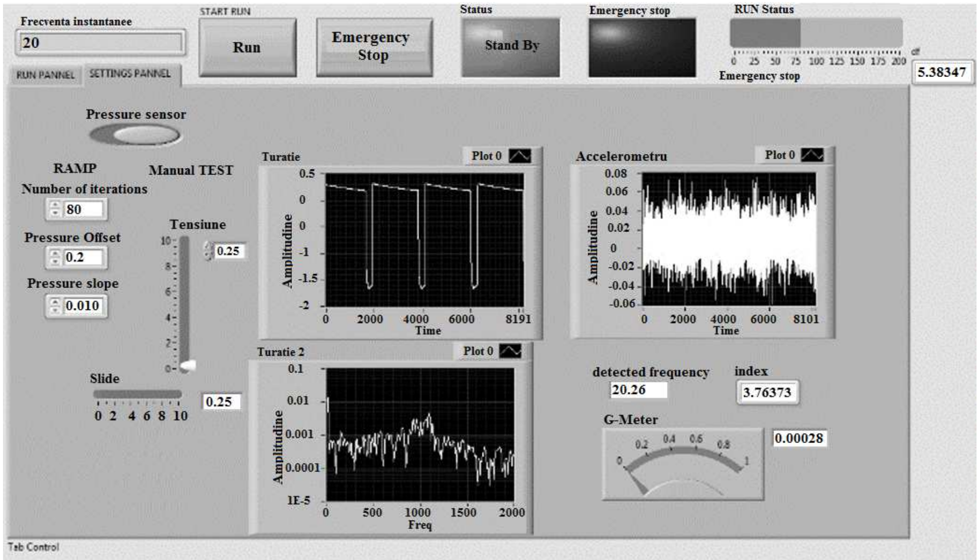

Fig. 2. The settings interface

3. DEMONSTRATION OF BALANCING PROTOTYPE MACHINE FUNCTIONALITY

3.1 Samples

In order to demonstrate the functionality of the prototype 10 CHRA for a 1.3 L gasoline engine were used.

3.2 Measurements

Parts were marked with a number with white paint from 1 to 10 same as in fig. 3a.

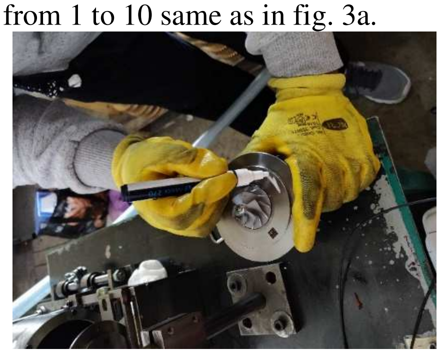

Fig. 3a Marking the parts with numbers

One blade from compressor wheel was painted completely in white in order to provide the optical "0" signal same as in fig. 3b.

For Gage R&R data processing was used Minitab version 17 with Anova-Nested method. The results are presented in table 1 and fig.4.[8]

Error rate of 7.52% of measurements are below 25% as result, the equipment can be considered as repeatable.

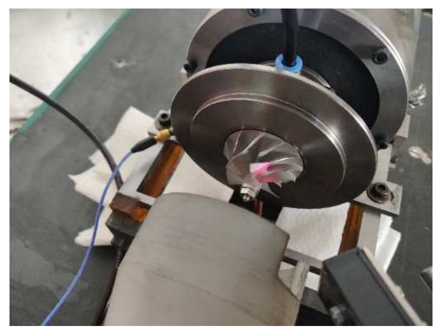

Fig. 3b Painted compressor blade for optical speed measurement.

Table 1

Gage R&R results

Source	Standard derivate (SD)	Study Var. (6 × SD)	Study Var. % (%SV)
Total Gage R&R	0.028224	0.16934	7.52
Repeatability	0.028224	0.16934	7.52

3.3 Balancing

At the operating speeds of most car turbines of 50000 - 420000 rpm (833 - 7000 Hz) balancing is a key element in the manufacture of turbines to achieve the life specified by the manufacturer. Imbalances reduce the life of the turbine by causing unwanted vibrations that can destroy the bearings, even leading to breakage of the shaft and even causing the destruction of the engine by oil in the combustion chamber.

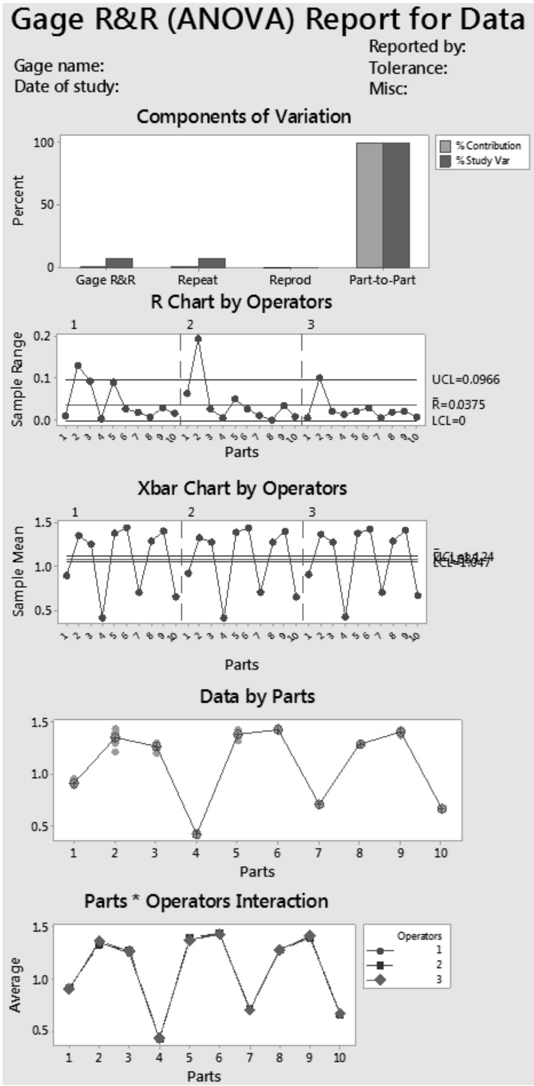

Fig. 4. Gage R&R report from Minitab

The purpose of balancing is to reduce the imbalance value as much as possible resulting in a part with low vibrations, as a result of an extended service life.

The assembly of the parts in the measuring device was performed by attaching the flange with the accelerometer on the oil outlet area of the turbine.

The balancing was performed manually by removing material with a Dremel type grinding tool with a spherical diamond stone with a diameter of 3 mm as in figure 5.

After each action of removing the material, the piece was remeasured and, if necessary, the material was removed again according to the changes in imbalance. For balancing to be successful, the vibration values recorded by the accelerometer after removal of the material must be below initial one.

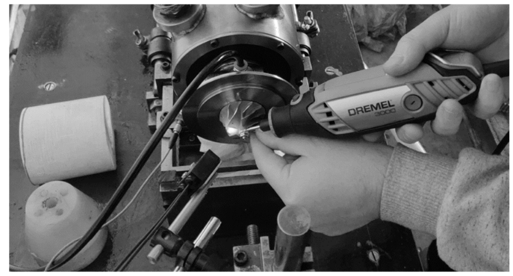

Fig. 5. Removing material for balancing

4. RESULTS

Below (figure 6-15) are the results for balancing each of those 10 CHRA. On X axis are the frequency in Hz and on Y axis are the vibration in G.

The max value of the vibration was between 0.42-1.45 G before balancing and after the value dropped to 0.25- 0.72 G.

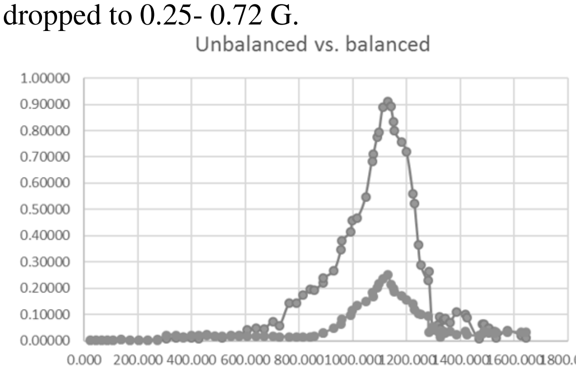

Fig. 6. Measurements results for CHRA 1

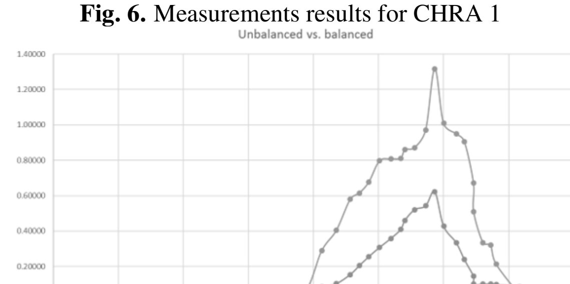

Fig. 7. Measurements results for CHRA 2

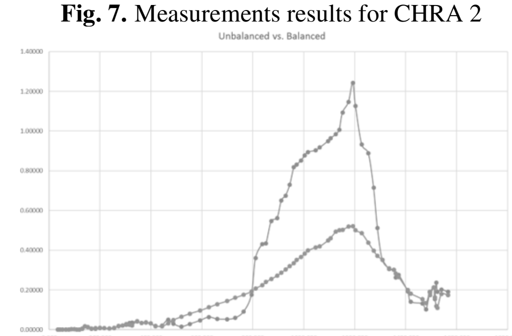

Fig. 8. Measurements results for CHRA 3

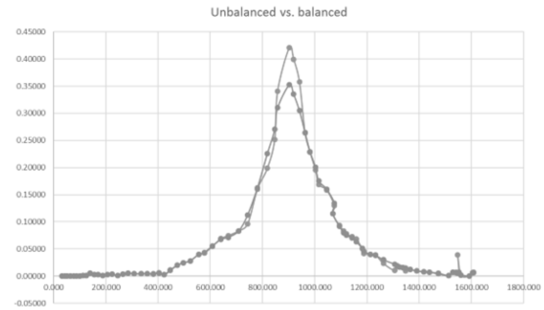

Fig. 9. Measurements results for CHRA 4

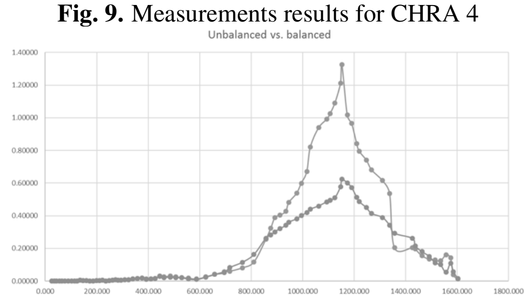

Fig. 10. Measurements results for CHRA 5

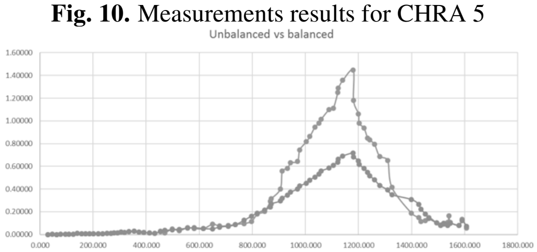

Fig. 11. Measurements results for CHRA 6

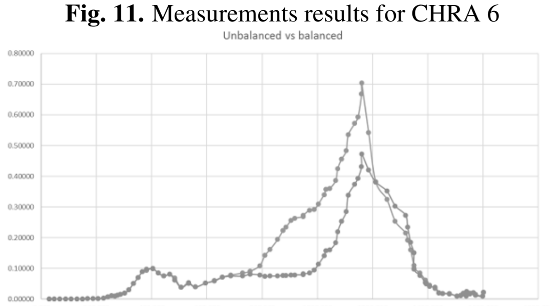

Fig. 12. Measurements results for CHRA 7

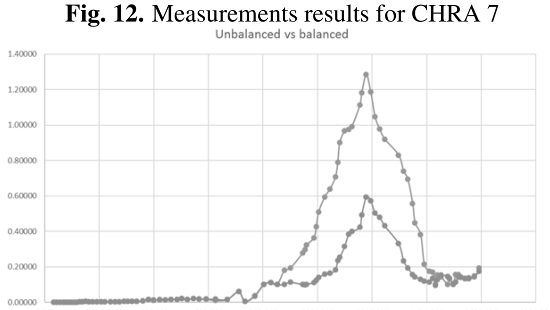

Fig. 13. Measurements results for CHRA 8

For all figures the higher peaks are the initial unbalance and second, lower peak is the residual unbalance after balancing was performed. Gauge R&R data vas processed using Minitab with Anova method.

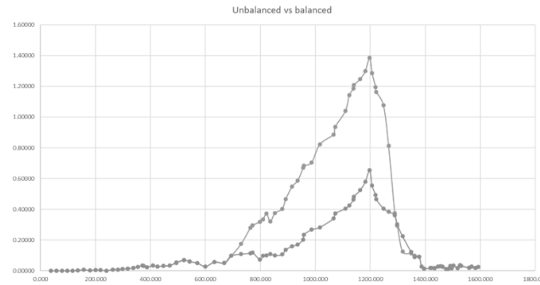

Fig. 14. Measurements results for CHRA 9

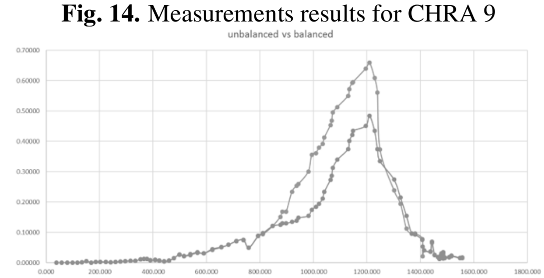

Fig. 15. Measurements results for CHRA 10

The unbalance of the parts was initially between 0.41-1.455 g. After balancing the G levels were reduce with 17-72 %. The standard deviation of the measurements was 0.028224.

4. CONCLUSIONS

The prototype has very good repeatability, Gauge R&R being below the 16% limit. The optical speed measurement system lost the signal around the frequency of 1700-1800 Hz (102000-108000 rpm), as a result the system can be improved by changing the optical sensor with another measurement system with a response speed over 2000 Hz.

All tracks except track 4 had the largest imbalance in the range measured around 1200Hz. CHRA 4 had an imbalance around 900Hz, this is common in series production, some CHRA due to several factors have different responses in measurement. These factors in the series production of car turbines can be:

- The chain of dimensions of the bearing components (axial and radial); Axial dimensions could influence the axial load with high transmissivity to center housing influencing the unbalance readings. Radial tolerance chain can influence the vibration in horizontal and vertical plane. To correlate the chain of dimensions to level of unbalance was a subject of many studies conducted by large manufacturers with inconclusive results due to the high complexity in a very difficult to predict environment electrohydrodynamic bearings with flexible shafts at different rotation speed. Besides that the gaps between components can change at every re-assembly due to material tenacity, soft-hard material contacts.

- The variability of the play between the shaft and the bearing and between the bearing and the housing;
- Tightening moment of the nut on the assembly line
- Rework - disassembly and reassembly or change of the nut
- Different mass of the cast part (bearing housing) from the rest of the batch.

5. ABBREVIATIONS

MRC - material removal curve
CHRA - center housing rotating assembly
CW - compressor wheel
FEA - finite element analysis
VSR – vibration sorting rig

6. REFERENCES

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Demonstrarea funcționalității a masinii prototip de echilibrat turbosuflante în condiții de funcționare relevante

Rezumat: Un turbocompresor trebuie măsurat pe un VSR (instalație de sortare a vibrațiilor) și echilibrat pentru a obține un produs durabil care să reziste la durata de viață specificată de producător (în general, garanția de 1 sau 2 ani depinde de producător sau de tipul de turbocompresor). Dezechilibrul rotorului turbocompresorului creează întotdeauna vibrații care ar putea fi foarte distructive pentru rulment. Pentru demonstrarea funcționalității prototipului de echilibrare manuală a turbocompresoarelor au fost utilizate 10 turbocompresoare. Mașina de echilibrare prototip a fost construită în jurul unui sistem DAQ My Rio (versiunea studențească), folosind Labview 2014 pentru programarea interfeței, controlului și salvarea datelor. Datele de măsurare R&R sunt procesate folosind Minitab cu metoda Anova. Dezechilibrul pieselor a fost inițial între 0,41-1,455 g. După echilibrare, nivelurile de G au fost reduse cu 17-72%. Abaterea standard a măsurătorilor a fost 0,028224.

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