COMPROMETIDA COM A PROMOÇÃO DO DESENVOLVIMENTO DA ENGENHARIA E DAS CIÊNCIAS MECÂNICAS

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ON-LINE PRODUCT DIMENSION VERIFICATION AND CORRECTIONS ON CNC MACHINE TOOL

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Abstract. *Constant computer hardware and software development resulted in rigid demands for dimensional accuracy of the product. According to this it is important to verify product dimensions during the manufacturing process. Together with special software on CNC-controller and touch probe head, on-line product dimension verification on CNC-machine tool center can be done, which has direct impact on better product quality and efficiency of the process. In the paper we present product and its critical accuracy demands which lead to numerous problems (some of them are described in paper) regarding quality manufacturing of the product and productivity as well. In this respect, employment of touch probe head on CNC-machine tool significantly improves quality of the products and efficiency of the process; therefore some probe head specifications are given as well.*

Keywords: *on-line product dimension verification, touch probe head, corrections, CNC-machine tool*

1. INTRODUCTION

A majority of all manufacturing companies are facing rigid demands to meet today's global competition. There are a number of methods, which are recommending continuous improvements into production lines; howsoever, mostly all of them are based on lean production philosophy. Considerations and decisions made regarding investments and development actions should apply also an adequate knowledge in order to achieve the highest productivity (Johnson, Anderson and Stahl, 2008). Apart from rigid production demands, product verification process plays significant role in today's manufacturing process. Tendency towards all-products (product dimension inspection, material properties inspection, etc.) verification opens another chapter in manufacturing process, because verification steps should not be synonyms for production bottlenecks, but should be fully integrated into manufacturing process. Fully automated verification process is still hard to achieve even nowadays, although recent software and hardware development constantly reducing number of labor force for inspection. Still, some highly qualified labor force will be needed in long term period, because lean production is by its definition flexible and can be achieved only with technology and knowledge investment in order to achieve the highest efficiency benefits in production line (Johnson, Anderson and Stahl, 2008).

2. PRODUCT DESCRIPTION

In this paper we will focus on special part production of the vacuum pump used in car engine for one of well-known automotive company. Origin for machining of the pump is aluminum alloy cast, which already has all significant features (holes, grooves, etc) in order to minimize pure cutting time and increase cutting tool life. Figure 1 presents vacuum pump with two machined sides, where shallow side of the pump is together with other assembled semi-part designed to form oil mist for drive shaft smearing. On another side this rotating drive shaft (deeper chamber) create vacuum, which consequently opens or closes cylinder-piston type connected to the braking jaws. Figure 2 presents production drawings of the vacuum pump with four bores denoted with MH1, MH2, MH3 and MH4 sign. Critical diameter of the holes, shape and position of the holes (ø8 mm), are dependant according to each other and to the primary hole F (ø15,025 mm), which is going through housing. All small bores (ø8 mm) are perpendicular to base plane D (oil mist side of the pump) and parallel to axis, which going through hole F (ø15,025 mm). These demands essentially characterize sequence of milling and drilling processes on the part as well as fixture for the products and clamping system for the CNC-machine tool bed. Manufacturing process should be therefore very precise and stable in order to satisfy all rigid dimension specifications of the product.

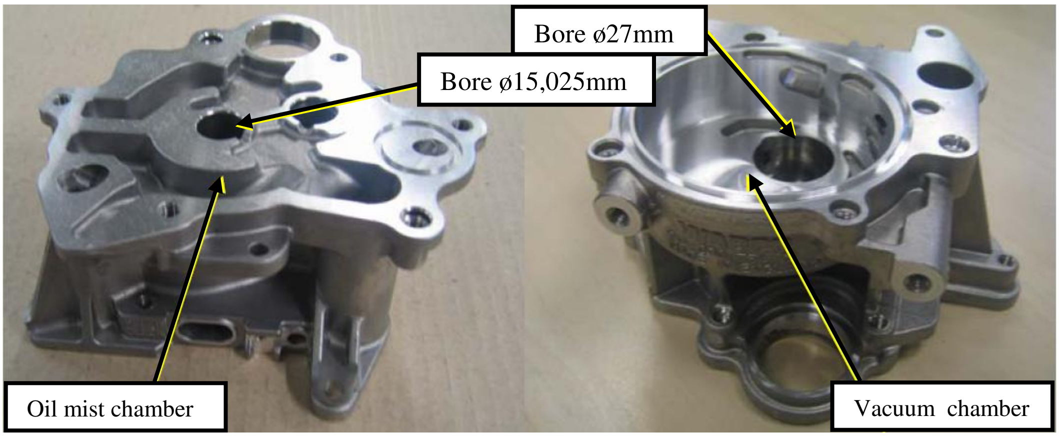

Fig. 1: Machined aluminum cast of the vacuum pump

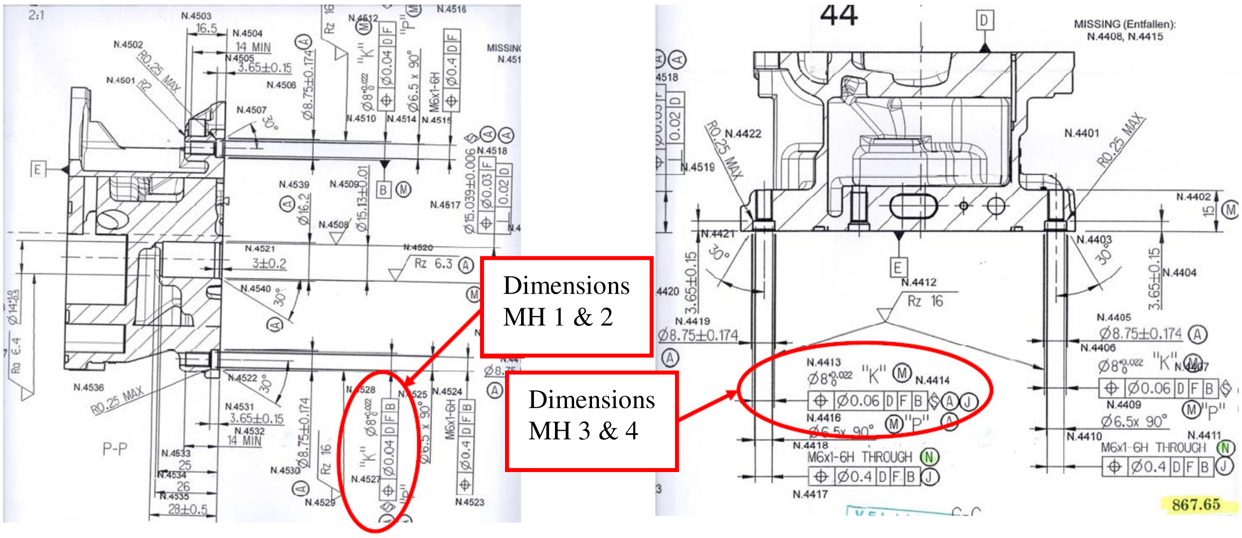

Fig. 2: Production drawings of the vacuum pump with critical features

3. MANUFATURING OPERATIONS

As it was mentioned, tight tolerance window of the boreholes dictated stable and very precisely defined manufacturing process. Product manufacturing and due to productivity issue leads company to choose double-spindle CNC-machine tool center Chiron DZ 15 KW, where special fixture application (see Fig. 3) makes possible to perform cutting operations on two products at a time. CNC-machine tool could also rotate fixture around Y-axis (B-axis), which enables cutting operations on both sides without overstretching, which is essential condition to meet all tolerance demands on the product. Regarding to complex shapes of the vacuum pump casting, fixture is complex as well. It has three clamping jaws and two clamping tongs (see Fig. 3), which movements are controlled by NC-code and CNC-controller unit. According product specifications and properties, manufacturing process employ 16 different cutting tools. First manufacturing steps were done with 16 different cutting tools, optimization process bring company 4 different cutting tools, which are all tailor-made (see Fig. 4).

Fig. 3: Fixture device

Fig. 4: Tailor-made cutting tool

Time consumption for one cutting tool rotation is around 4 seconds, thus a lot of time were lost in non-cutting time, when 16 different cutting tools were in use. After optimization and implementation of tailor-made cutting tools, non-cutting time was reduced by factor 4, consequently resulted in more than 300 more manufactured products per week. Productivity was therefore significantly better. As was stated before, workpiece has already all significant features (holes, grooves, etc) placed in casting, in order to lengthened tool life and minimize pure cutting time. In this case pure cutting time was under 5 s, which is very good result according to quite a few machined areas onto the product.

4. VERIFYIG PROCESS

In discussed case, verifying process was optimized and modificated several times. At the beginning dimension inspection process were done on some products, which were randomly selected from the production line, and were based on labor force and simple inspection devices. Those inspection devices were mainly developed in the company and therefore with a lot of imperfections, which present unbridgeable obstacles for automatic inspection process set up. Same problem was encountered, when dimension verifications were done on coordinate measuring machine (CMM). Beside that inspection process in any of mentioned cases were slow and did not offer any possibilities for hundred percent inspections of the manufactured products. Due to rigorous tolerances and consequently due to scrap products, customers' new requirement envisaged necessity some kind of dimension inspection. In order to satisfy this request company implemented totally new verifying process, which dimensionally check all manufactured products and at the same time do not impede or create bottlenecks in manufacturing process line. In the next few lines we will briefly present some past verifying solutions, (which eventually turned out to be improper), with some accompanied problems as well.

4.1. Pin bore inspection

Due to strict tolerance demands of the bores, company tried several modes for bore diameter inspection. All of them were based on pin bore inspection. Fundamentally these methods are good, but have a lot of disadvantages. The main impediment is connected with fact that measurements are slow and could be frequently influenced by random errors, which simply have coincidental origin (either arose by manufacturing process or by inspection process or both and are presented later in the text) (Sokovic, Cedilnik and Kopac, 2007). Therefore these inspection methods are not fully trustworthy and due to that, these methods are also not fully convenient for automatization. On a Fig. 5 we presented bore inspection ($ø8,0^{+0,022}$ mm) with pin according to "go/no go" principle. Firstly, for this kind of bore dimension inspection is very hard to manufacture accurate diameter of the pin. Secondly, this process is very slow, thus hundred percent control is almost impossible. Beside that process itself does not offer totally reliable results, because it depends too much to the judgment of the (experienced) worker.

Fig. 5: Pin bore inspection

4.2. Measurements on CMM

Another mode for product dimension verification presents coordinate measuring machine (CMM), Fig. 6. In described case this solution was far from perfect regarding to verification speed, and perfect if we take into account verification results. At the beginning verification process took for one product nearly 12 minutes. Through some knowledge, which was mainly acquired by practical work and product manufacturing process improvements, verification process was much optimized (systematic verification approach, and only critical dimension inspection), thus time needed for verification of one product was significantly reduced and at the end last 3 minutes. Although, the time needed for verification was substantially reduced, this method was still not quick enough to make feasible all-product verification.

Fig. 6: CMM Zeiss

5. SOME PROCESS FINDINGS

5.1. Drilling problems

At the initial mass production series, company faced some quality problems connected with drills and with drilling process. Every now and then, strange coincidence or failure caused, that some products from the production line did not meet bore dimensional standards. These scrap products were randomly distributed over production series and were not connected to any reason such as tool wear, end of tool life, tool replacement, interrupted (stopped) manufacturing process,… We could not detect any noteworthy signal, which could be characterized as a cause for scrap products. Eventually, if not luckily, we found out the cause for inaccurate bore dimensions. One cause for bore dimension incorrectnes was chips, which were not eliminated from the drills cutting zone. Through drilling process, every now and then some chips, which were not removed from the drills cutting edge, welded with tool, which consequently caused improper bore dimensions. Some reason for chip welding effect could be found in aluminum alloy material properties of the cast and in fact, that cooling lubrication fluid did not remove all chips from the cutting zone. Considering that, new and more powerful pumps for cooling lubrication fluid were installed in order to supply higher fluid pressure to the cutting zone. Regarding described problems it should be clarified, that at that time on-line dimension verification was not yet implemented into production line, thus took us a much longer time to define the reason for inaccurate bore dimension. In fact, described problems show another motive why product verification system should be implemented into the production line.

5.2. CNC-machine tool inaccuracy

During product inspection we detected some dimensional problems on products, which originate directly from the CNC machine tool geometric accuracy. Fact is, that at every CNC-machine tool center some machine tool errors and deviations are and should be taken into consideration. In described case, not the best CNC-machine tool was used for product manufacturing, thus so much more attention should be paid to the errors and deviations which originate from the CNC-machine tool. Ballbar tests, which were made on CNC-machine tool, indicate squarness error between two rectangular X and Y-axes, error which has direct influence on overall geometric accuracy of the CNC machine tool. In this place should be mentioned also unavoidable problems regarding tool clamping system, which consequently swing rotating tool (cutting tool is not precisely in the centre of the clamping system) and therefore have affect on product/bore accuracy and dimensions. Taken as a whole, we were aware of mentioned problems, because knowledge of possible error origin guide us to minimize those errors, although they could not be in any way annulled (Cedilnik, Sokovic and Jurkovic, 2006).

5.3. Cooling lubrication fluid temperature problems

Before implementation system for all-product verification, we spent a lot of time making researches to found out reason for product dimension incorrectness. Quite a few products in the series did not meet peaked tolerance standards, although we with certain trust eliminate all above mentioned problems origin. Because of that, we start extensive investigation, where dimensional accuracy was checked according to product position on fixture and number of identical fixtures. At once, company manufactures 2 products in both sides (2-nests in one fixture and 4 machined areas), assuming that product position on a fixture may affect on dimensional accuracy problems, we faced. Measurements on CMM and some additional experiments did not show any significant deviations on critical dimensions regarding product position on fixture. Multiple fixtures are also not key parameter for scrap products, because critical dimension repeatability according position on multiple fixtures, are surprisingly good; see Fig. 7. Below in this text, we present a factor, which turned out to be crucial parameter for quality products manufacturing.

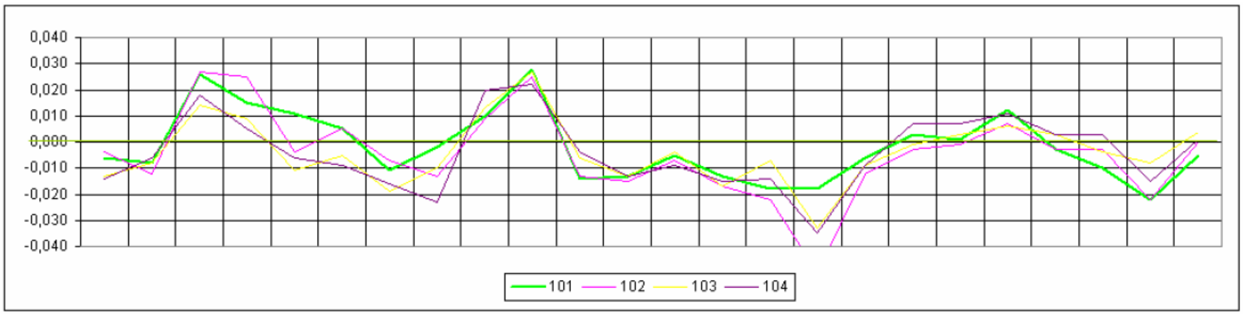

Fig. 7: Accuracy measurements according to product position (4 possible positions) on multiple fixtures

We are all very well acquainted with facts concerning temperature effect on material. Regarding material properties different thermal expansion coefficient for different materials is known (thermal expansion coefficient for CNC-machine tool and for aluminum alloy casting is different). In the face of that, it is very clear, that material elongation and shrinking (technical term: *machine growing*) under temperature loads have negative effect on any process, which should be stable. Thus, in our case these unstable conditions presented huge manufacturing problems, which we analyzed in details (and described below) in order to be able to meet high quality production standards of the product.

In next few lines we will describe some case findings which led us to short term solutions and consequently also to long term solutions regarding controlling cooling lubrication fluid temperature and thus improving the manufacturing process as well as improving product quality. After a few initial checks of the investigation process, we starting to realize that cooling lubrication fluid temperature is parameter which should be carefully observed. At that time, product manufacturing process was already very much automatized (although product quality was not at the highest level), like sub-system, which was designed to level cooling lubrication fluid in tank in CNC-machine tool. Cutting operations on CNC-machine tool should be constantly cooled and lubricated with special cooling lubrication fluid, which consists 94 % of water, the rest is a concentrate. During operation of CNC-machine tool, cooling lubrication fluid is circulating in machine, what has direct influence on water evaporation from the system. Therefore, water and the concentrate should be in right proportion supplemented to the tank of the cooling system on CNC-machine tool. Until cooling lubrication fluid temperature was not detected, system simply supplements water and concentrate, when level cooling lubrication fluid was too low. At one time in system is add approximately 200 liters of water (tank volume is about 5 m^3). Due to fresh and cooler water supplemented in the system, cooling lubrication fluid temperature dropped for almost 3 degrees, and warmed up to original temperature in about 3 hour time; see Fig. 8.

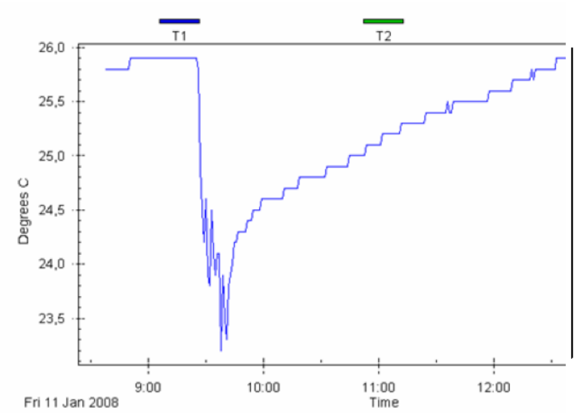

Fig. 8: Temperature measurement of the cooling lubrication fluid (before and after the water addition)

Change of temperature has of course effect on working machine temperature as well as machine modules; ballscrews, guidelines, machine bed, etc, each of them were probably differently affected by the variation of temperature. Measurement of critical product dimensions on CMM shows that machine growing effect was the main and actually the only reason (position depending errors originated from fixture were in this case negligible) for scrap products in the company. In order to solve this problem water heater warms the water for pouring to 25 degrees Celsius, and after that was added to the cooling system. Beside that just small amount of cooling lubrication fluid was added to the system in order to minimize machine growing effects.

6. FINAL SOLUTION

Despite all findings, which were presented so far in this text, there exist also some impediments, which were braking further process improvements and consequently better productivity results. Through process investigation and detailed analysis we overcame many barriers and solve a few problems in order to improve quality of the product and production process as well. Nevertheless, we could not solve the problem related to CNC machine tool warming up time. Working temperature of the CNC-machine tool centre is around 26^{o}C (see Fig. 8) and time needed to reach machine working temperature from idle mode is around 3 hours. During that time, obviously CNC machine tool centre was not in operational mode. Apart from that we still produce some scrap products, which we knew that are directly connected with CNC-machine tool centre and its geometric inaccuracy. Because of all described problems, we were determined to find long term solution, which will be an answer to all described impediments or process imperfections. After searching for options, which could be bought on market, we decided to get equipped with touch probe head from very well known UK manufacturer.

6.1. Touch probe head specifications

Touch probe head (see Fig. 10) is designed to automate part set-up and in-cycle gagging in small machine-tool centers and high-speed cutting machines. Using this touch probe head could reduce set-up times up to 90% and at the same time can reduce scrap products, which were caused by setting errors. Benefits could be seen also in lowered costs and improved process control, which were crucial factor in our case. Mentioned touch probe head uses miniaturized electronics resulting in an ultra-compact probe that measures only 40 mm diameter and 50 mm length, but delivers metrology performance of 1µm repeatability. It has been specifically designed for probing on small machining centers and machines fitted with small HSK and small-taper spindles. For these smaller machines, the length of the probe head matches typical tooling lengths, bringing the significant advantages of probing to such machines for the first time.

Fig. 10: Probe head

The touch probe head features a 360-degree optical transmission system with a range of up to 3 meters, allowing probe operation in any spindle orientation. Power for signal transmission is taken from inside battery, which were firstly lasting only about 200 hours. With software corrections (probe head is now during non-operational function turned off) battery life-time is now prolonged to 800 hours. User programmable parameters make this probe head simple to optimize for specific machine applications. The probe software is programmable through trigger-logic, a unique and simple programming method, allowing users to program probe options without accessing probe internals, eliminating the risk of damage due to coolant and debris ingress. It incorporates also a digital filter which makes the system highly resistant to shocks and vibration as well (Renishaw, 2008, New ultra-compact OMP40, 2003 and Probe inspects machine tools, 2002). So this probe head is ideal tool to solve our machining problems.

6.2. Our benefits using touch probe head

Implementation of touch probe head onto CNC-machine tool gives us opportunity to check critical dimensions after certain drilling or milling operation was finished. First step in our process is drilling bore through housing (ø14,75 mm, see Fig. 2). In next step precise center position with touch probe head OMP 40-2 was determined. According to this position, bore with diameter ø27 mm (see Fig. 2) in chamber side of the pump is drilled. Regarding to center position of the bore with diameter ø14,75 mm, a concentric bore (ø15,025 mm) on oil mist side of the pump is drilled. In this manner same axis line of the main bores on the product is assured. Shape and position of the other bores (ø8 mm) on the oil mist side are primary dependant to hole ø15,025 mm and also according to each other. In another way that means, this manufacturing method secure also, that all MH_x bores are parallel to axis going through hole F (ø15,025 mm) as well. Evidently, manufacturing process with described probe head, makes feasible to meet all high dimension standards of the product. Because on-line measurements on single product can be made, on-line corrections in numerical control module (NC-code) for each product on the fixture can be performed. Undoubtedly, touch probe head gives us almost hundred percent controls onto the product manufacturing process.

7. CONCLUSION

In this text, authors wanted to show problems regarding manufacturing and verification process of very complex product. Due to rigid tolerance demands quality product production is far from easy to acieve. Great process impediments demand knowledge, research work, detailed result analysis and people to overcome them. Progress improvements in such caes are usually evolution (small) steps mainly based on knowledge acquired by practical work, rather than giant leaps. At the beginning of this project nobody would imagine, that before implementation of probe head, controlling cooling lubrication fluid temperature, was actually the key factor for quality product production. At the same time we should also emphasize, that some problems with scrap products also originate from CNC-machine tool geometric inaccuracy. After probe head implementation, significant greater process control was achieved, thus consequently better product quality and less scrap products. Although production cycle time is due to on-line measurement lengthen for about 10 % according to a production process without probe head, more good products are made per week. Number of scrap products are lowered from 7% per week before implementation of probe head to just 1% per week after implementation. At the same time we lowered maintenance costs, as well as machine downtime from 15 hours per week to just 3 hours per week, which is really significant improvement. At the end we want to clarify, that investment is after 3 months already paid off and there is evidently still some room for improvements in this process.

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