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Design, Manufacture and Testing of On-Site Taper Grinding Machine

Prof.H. A. Khande[1], Abhishek Kumar Srivastava[2], Aniket Bhalerao[3], Manoj Mane[4], Yash Mandlik[5]

[1]*Professor,Mechanical Department*, *SKNCOE, hakhande@sinhgad.edu*

[2]*Student,Mechanical Department*, *SKNCOE, abhiks211@gmail.com*

[3]*Student,Mechanical Department*, *SKNCOE, aniketb153@gmail.com*

[4]*Student,Mechanical Department*, *SKNCOE, manojmane25@gmail.com*

[5]*Student,Mechanical Department*, *SKNCOE, yashmandlik47@gmail.com*

ABSTRACT

A portable taper grinding machine has been designed and manufactured to regrind the faulty BT tapers of VMC/HMC spindles. This machine is designed to regrind BT30, BT40, BT50 spindles. This machine saves about 3-6 days which were required for disassembling, transportation to service centre, regrinding, testing, transportation back to client and assembling. Cost of transportation and servicing is reduced to 30,000-40,000 which was up to 80,000 by conventional method. If the machine is disassembled to remove to spindle then bearings have to be replaced, irrespective of their condition, but by this method there is no need to replace the bearing. Less lead time, saves money, fast, reliable services, precision results, the machine can offer unique services "On site taper grinding" for faulty taper bores of VMC/HMC spindles. As the machine is portable it can be taken to any location and spindle tapers can be ground back to specifications, to ensure greater concentricity to the bearings and thus minimum run out. Blue matching test is being performed to ensure proper regrinding of the spindle to the required specifications. Regrinding in place also eliminates the tear down required to remove the spindle and reduces the down time normally experienced to save the money. The cost estimation of machine is approximately 7.5 lacs. Analysis of the machine was performed, the results shows that the deformation and stresses were within limits.

Keywords: *On-Site Taper grinding machine, BT tapers, Blue matching.*

1. INTRODUCTION

1.1. Spindle Taper Problems-

There are four major spindle taper problems with which all manufacturers need to be concerned-

The first taper problem is bellmouthing. Bellmouthing takes place naturally as the spindle taper wears during continued use. It usually occurs at the large diameter of the taper, leaving contact only at the small diameter portion, which may account for fifty percent or even less of the total spindle taper contact area. This reduced contact leads to increased tool movement and greater tool runout.

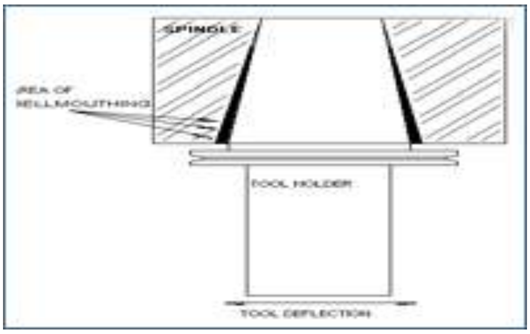

Figure-1: Bellmouthing of spindle

Because bellmouthing happens very gradually over a long period of time, it often goes unnoticed. The drawing (figure 1) below shows the area of wear (or bellmouthing) on the spindle taper. This lack of contact between the tool holder and the spindle will first begin to show on the machine spindle taper (and tool holder) as fretting. This is easily seen by the eyes of the operator as rust colored areas, or spots. The machine operator will begin to observe such symptoms as tool chatter on work piece surfaces, carbide inserts chipping at the cutting edge and inconsistent bore sizes.

The second taper problem is machine malfunction or operator error.This can cause a tool holder to spin inside the spindle taper. This condition leads to a buildup of galled material, which completely eliminates contact of the tool with the taper surface. Although attempts to grind away the material buildup by hand can increase taper contact, the increase is usually not sufficient to achieve satisfactory work piece quality. Furthermore, such grinding can irreparably damage (Figure 3) an otherwise repairable spindle.

The third taper problem is weak tool retention. This problem can cause tool chatter, even though the spindle taper is acceptable. Unchecked, the condition inevitably leads to premature taper wear of the machine spindle and of the tool holder.

The fourth taper problem is the use of worn tool holders. Using worn tool holders in a new, rebuilt, or reground spindle will cause premature spindle taper wear, due to inefficient contact between the tool and the taper. Tool holder condition is as important as spindle condition.

1.2. Construction of machine-

The machine grinding tool can be moved in transverse(depth of cut) as well as in longitudinal direction(feed). The grinding tool angle can be set along the BT tapers angle. The total feed in longitudinal direction is 150mm and in transverse direction is 65mm and the angle can be set +/- 11 degrees about pivot point.

1.3. Working of machine –

First of all taper angle is set along the BT taper with the help of pivot assembly and swivel plate and the arrangement is locked, so as to keep the same angle throughout the complete operation.

The depth of cut in transverse direction is give with the help of anti-backlash lead screw, which is operated manually with the help of engraved dial. The precise transverse motion is guided by the LM blocks and LM rail arrangement.

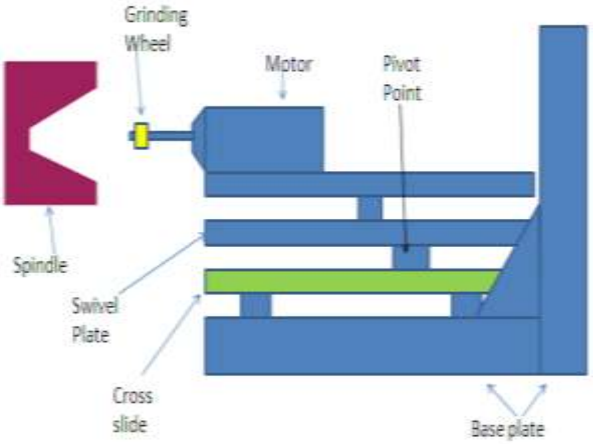

Figure-2: Block Diagram of machine

Reasons for using LM blocks are-

There is no stick-slip condition in LM rails due to rolling contact between mating surfaces. It has lesser heat generation due to point contact. Capable to maintain accuracy for a prolonged time. It has low cost , easily available.

The feed to the grinding wheel is given with help of the ball screw which is driven by stepper motor for automatic to and fro motion feed. This linear motion is also guided by the LM blocks.

The tool rotation is given by the DC motor having maximum 30,000 rpm. This motor is operated at 8000 rpm for grinding operation.

1.4. Calculations

N = Speed of tool = 8000 rpm

D = Diameter of wheel = 30 mm

t = Depth of traverse grinding = 0.05 mm per pass

v = Velocity = (π*D*N) / 60 = (π*30*9000) / 60,000= 14.137 m/s

Q = (π*Dw*t*ft) /1000= (π*80*0.05*1000) /1000 = 12.56 cc/min

(For tool steel for 0.05 mm depth of grinding)

Nw = Speed of workpiece = 1000rpm

Dw = Diameter of workpiece = 80 mm

ft = Table traverse feed rate = 1000mm/min

Material removal rate per minute(Traverse grinding),

U = Average unit power for grinding = 0.65

P = Power = Q*U = 12.56*.65 = 8.168 KW

Ft = Tangential cutting force = 102*P/V = 102*8.168/14.137 = 58.933 kgf = 589.33 N≈ 600 N (approx)

T = Torque at spindle = 975*P/N = 975*8.168/9000= 0.884 kgf m = 8.84 Nm

a. *Total length of LM Rail in longitudinal direction* =
(2*length of LM Block) + distance between lm blocks + feed in longitudinal direction+ length of grinding wheel

= (2*91) + 59 + 150 + 30 = 421 mm

Distance between rails is taken as per standard calculated values from THK catalogue=151 mm

b. *Total length of LM Rail in transverse direction*
= length of LM Block + feed in transverse direction + Extra distance to avoid interference
= 105.7 + 65 + 109.3 = 280 mm

Distance between rails is taken as per standard calculated values from THK catalogue = 250 mm

c. *LM BLOCKS SELECTION (Horizontal condition)-*

Static safety factors are - Fsi = 45.25; Fsm=6.45
Both are acceptable in static conditions

d. *LM BLOCKS SELECTION (Vertical condition) –*

Static safety factors are - Fsi = 44.74; Fsm=2.834

Both factors are acceptable in static conditions

e. *Calculations for pivot bearing-*
Radial Force, Fr=2992.305 N
Axial Load, Fa=294.3 N
Radial Force=F/2+ force due to momentum of the moving parts

Force due to Momentum=(Mass of moving parts * velocity of moving parts)/time =20*(1/60)/8 =0.04166N

Radial Force =5984.61/2 + 0.04166 =2992.3466 N
Radial Force, Fr=2992.3466 N
The weight of the machine =50 kg
So we took axial load on the pivot=30 Kg
Therefore the Axial load= 30*9.81=294.3 N
Axial Load, Fa=294.3 N

Equivalent dynamic Load,
P=X*Fr +Y*Fa ; P=1*2.992 KN
P=2.992 KN
FoS=C0/P ;FoS=6.55/2.992
FoS=2.17

1.5. Manufacturing

Most of the required parts were outsourced to various companies. The material used for the base plate and the vertical plate was Aluminium as our goal was to minimize the total weight of the machine. These plates were manufactured with the help of a VMC. The plates were then anodized so as to increase their resistance to scratches due to abrasives. As the LM rails are fixed on to the base plate, we also needed the plates to be perfectly flat which would otherwise lead to a loss in the accuracy of the machine. Hence, the plates were ground so as to obtain a good surface finish and flatness of up to 0.5 microns. Furthermore, to obtain further weight reduction, some amount of material was removed from the plates. This was obtained with the help of water jet machining. As these holes were not required to have perfect dimensions, water jet machining was suitable for our requirements. We decided against milling and wire cutting as it would have been time consuming, difficult and very costly.

The material used for the plates supporting the wheel and the plates used for the cross feed, was Steel. Steel was used as we needed the plates to be able to withstand the cutting forces and the vibrations acting on them. These plates were also manufactured with the help of a VMC. They were black anodized so as to increase the surface hardness. This was required as it would further help the plates in withstanding the cutting forces and vibrations and also protect them from the debris generated during grinding. These plates were also required to be perfectly flat and a flatness of 0.5 microns was maintained.

The ribs are made up of Steel. The ribs are instrumental in transferring the weight of the machine along with the cutting forces and their vibrations, to the vertical base plate, when the machine is operated in the vertical condition. As these forces have a considerable magnitude, we concluded that steel was a suitable material for the ribs. The ribs were milled with the help of a VMC and were also black anodized to increase the surface hardness.

1.6. Analysis

Structural analysis of various machine parts ensured safe design of the parts. Tetra mesh used for meshing. Quality checks like Jacobian, Tetra collapse, Aspect ratio in suitable values ensured quality of mesh. Hypermesh was used for meshing and Optistruct for post processing. Factor of safety of 5 was ensured in stress results and a deformation value of 0.1 mm was considered safe.

Parts base plate, angle plate, spindle plate, right angle plate (rib) and pivot were analyzed and proved to be safe. The analysis was done both in horizontal and vertical working condition of the machine. Forces considered included cutting force, force due to weight, moment due to cutting force and moment due to weight in vertical condition.

1.7. Inspection

The quality of the taper is measured using various tests. These tests are done before taper grinding to judge the condition of the taper and after the grinding to get confirmation of good quality taper. Important tests done are Blue matching test and Mandrel run out test. These test are important for assessing taper quality.

Blue Matching -

A thin coating of Prussian blue is applied (usually with a paint brush) on the insert before the matching is done with the spindle. If the Prussian blue (generally called as just "blue") appears evenly on the mating area and with 80% of blue intact, it is considered good matching and thus expecting a good final product. Matching less than 80% is improper finish grinding and needs to be ground more and more than 80% shows more fit than required which can create jamming. No spindle would be finished blue matching , a term generally used by the tool makers in Asia. In other words, Prussian blue is considered as an integral part of tapered grinding. Engineer's blue is prepared by mixing Prussian blue with a non-drying oily material (for example, grease).Prussian blue is a dark blue pigment with the idealized chemical formula $Fe_7(CN)_{18}$.

Mandrel Run out -

Run-out is an inaccuracy of rotating mechanical systems. Here we use to check that the spindle's axis of rotation is in line with main axis. Run-out is measured using a dial indicator pressed against mandrel which is fitted in the spindle while it is turned. The dial indicator is pressed at a standard distance of 350 mm on the mandrel. And the spindle is given one full rotation. The maximum and minimum values on the dial are recorded. The difference is the run out for that spindle. Spindle run out around 10 micron signifies good quality taper grinding. Total indicated run-out (TIR) is a technician's term for the measured run-out.

1.8. Testing

We tested the machine at GL&V. It is a company which manufactures equipments for paper and pulp production, located at Alandi. The spindle in the horizontal boring machine had lost it’s taper and had to be reground. Due to the faulty taper, the company was unable to obtain repeatability at different lengths of the mandrel. The entire spindle was 3 meters in length. The taper was a BT50 taper. Before grinding, the radial run out obtained was 120 microns which, after grinding, was reduced to 15 microns.

2. Literature Review

2.1. Machining Time Required For Taper Grinding and Its Cost Analysis in G17-22U Grinding Machine.

An attempt is made to solve problems in the process flow in an alternator production plant. The plant had to outsource their partially machined shaft for tapper grinding for a certain rating of alternator. A small study was conducted for identifying is there any opportunity to do the operation within the plant. Next approach was to solve the problem with in the plant's available resource, with high quality and law cost. Machining time and labour cost was calculated. Finally the profit of the company for a certain period of time is calculated within the available data's. This attempt helped us to know about the production process of different rated alternators, working of different departments in the firm, problems faced by a company.

BHEL EML is recognized as the quality product manufacturer in its play ground. It has maintained an upper hand in terms of trust among customers and still holds the monopoly in certain fields. In very short span of operation BHEL EML has made major strides in this vital sector and has acquired a solid reputation for superior quality, high efficiency, reliable performance after sales service and quick serviceability In my training i could suggest a proposal which brings about 53000 Rs saving for the company after all constrain in the company. This proposal could help the company not to outsource their products to outside for tapper grinding result in smooth process flow and fast output.

2.2. Effect of Dressing on Internal Cylindrical Grinding

Performance of grinding operation is influenced by a variety of factors amongst which dressing process is the most important. Through the dressing process, the grinding wheel topography is produced. This affects, in turn, directly the grinding forces, workpiece surface quality and grinding wheel wear. This research aims to develop appropriate dressing strategies for small abrasive wheels in internal cylindrical grinding. For this purpose, three different dressing rollers, including an electroplated, a vitrified bond form roller and a cup-dresser, with four different grinding wheels, two CBN and two corundum wheels, were experimented. The studies on the ground surface roughness values and grindingforces prove the validity of the Schmitt-diagram in internal cylindrical grinding operations. When up-dressing, a finer workpiece surface was achieved as compared to the case of down-dressing. This is associated with higher grinding forces which are caused by the finer grinding wheel surface. Further investigation was carried out on the wear rate of CBN grinding wheels. However, no measurable wear was seen up to a specific material removal volume of 9700 mm^3/mm.

This research is concluded as follows: 1. The dressing and internal cylindrical grinding experiments with small vitrified CBN and corundum grinding wheels show that the Schmitt diagram is valid for small diameter grinding wheels. The dressing were carried out in both down and up dressing modes and Schmitt diagrams were verified in both modes. 2. The measurement of radial wear of the ceramic CBN grinding wheel after a long term experiment showed that the wear value of this wheel after removal volume of 9700 mm3/mm is negligible (less than 1μm). 3. Measurement of the topography of the CBN wheel shows that the grinding wheel after dressing is closed and need to cut a certain volume of material to become open. This leads to high grinding forces right after dressing. However, the forces decrease after a certain removal volume. 4. When using the small vitrified grinding wheels, sharpening or using relatively low feed rates after dressing at the beginning of the process is recommended. This is carried out to open the grinding wheel pores or resetting the bond material.

2.3. Monitoring and Optimization of lnternal Grinding Process

The grinding process is influenced by many factors such as grinding wheel characteristics, dressing conditions and of course grinding conditions. Therefore it is difficult to perform the grinding operation in an optimum state. In this study, in-process monitoring methods using power and acoustic emission sensors are proposed to detect malfunction in the internal grinding process. In addition, a new internal grinding cycle featuring rapid in-feed is proposed to minimize the grinding cycle time.

In order to establish the highly reliable monitoring system for the internal grinding process the applications of the power sensor and the AE sensor were proposed. With respect to power monitoring, it has been confirmed that the calculation of the tilse constant as wellas the dead time in the grinding process areeffective to determine the wheel life. The occurrence ofgrinding burn could be successfully detected by monitoring the sudden increase in grinding power. The IEsensor together with the grinding fluid coupling device proposed in this study was capable of detecting tP,3 chatte- vibration. The total grinding cycle that could be considerably reduced by applying the rapid infeed. The theoretical background for decreasing theamount or rapid infeed needed to minimize the transient state was given.

2.4. Review of high-performance grinding in precision manufacturing processes

The growth of quality demands in high-performance manufacturing requires new and improved manufacturing solutions that provide the best performances at a reasonable cost. Increased performance and reduced component cost have all been achieved in recent years, through the exploitation of advances of new precision manufacturing processes. The objectives of this paper refer to brief review of some basic aspects of grinding and to point out paradigms of contemporary high-speed grinding (HSG).

Nowadays, where quality and quantity in high-performance manufacturing processes are just as important as efficiency, grinding processes have to be re-designed. Economical and effective employment of HSG is limited to narrowed machining frame, which leads to optimum cost efficiency. The best HSG is only achieved by effective integrated quality management, which refers to on-line process monitoring system, multilevel error control, visualisation, in/post process measurements, automatic process optimisation and remote quality diagnosis. The broad aspects of integrated quality management exceed the frame of this paper. We have emphasized that increased grinding cutting speed is the most important factor in achieving improved quality, tool life and productivity. It should be further stressed that HSG has all attributes to bring it to the front position of grinding technology. However, despite this HSG has not achieved the dominance once expected. There are two main reasons why HSG has not had the envisaged impact on high-performance manufacturing. Firstly, due to high costs of machine-tools and grinding wheels and secondly due to a lack of fundamental process knowledge on how to use the process effectively.

2.5. Modelling and Simulation of Process-Machine Interaction in Grinding of Cemented Carbide Indexable Inserts.

In this paper, a method of modeling and simulation for process-machine interaction in grinding of cemented carbide indexable inserts was presented. A center coordinate adjusting method and a virtual grid method were adopted to model the topographies of grinding wheel. The methods proposed in this work take account of the random nature of abrasive grains and were able to avoid overlapping between abrasive grains in the binder in modeling. With the grinding wheel model at hand, a process model base on KSIM was able to generate forces as input data in process-machine interaction. A wheel-spindle structure was selected and modeled by means of finite element method. The dynamic characteristic of the model was then verified by experimental modal analysis, which proves to match well with the experimental results. The characteristic equation of the closed-loop dynamic grinding system was derived to account for the inner-relation of process and machine. A coupling simulation with an iteration algorithm was proposed to investigate the process and machine interaction. In the coupling approach, process and machine structure were dealt with in an integrated manner and interacted in synchronized cycles. Dynamic interaction of grinding forces and grinding wheel deformations were then investigated based on the proposed simulation method. It shows that the grinding wheel deformations have an influence on the cutting forces. The coupling method serves as a useful tool to understand well the interaction phenomenon in grinding of cemented carbide indexable inserts.

2.6. Performance Analysis of Cylindrical Grinding Process with a Portable Diagnostic Tool

This paper presents an approach to develop a diagnostic tool that can monitor the power drawn by the spindle motor using a power sensor and infeed of grinding wheel using a linear variable differential transformer (LVDT) in cylindrical grinding machine. A combination of spindle power and wheel infeed measurement enables the performance evaluation of grinding process. This evaluation suggests the possibility of optimizing the grinding cycle in order to enhance the efficiency of grinding process. The effectiveness of the developed in process, portable diagnostic tool is demonstrated with a case study.

This paper covered the development and application of a portable, in-process diagnostic tool for monitoring of grinding power and wheel infeed during cylindrical grinding, using a power cell and LVDT. The collected data is then used to evaluate the performance of the grinding process in terms of specific energy consumption in grinding. Future efforts are directed towards using this diagnostic tool for designing efficient grinding cycles for optimal use of grinding machines.

3. SUMMARY

Designing, manufacturing and analysis of machine is done and its testing has been successfully completed. Machine is satisfying the standard of the company and working well within the required specifications. The estimated cost of machine is approximately 7.5 lacs. The company is planning to make 2 more similar machines, with further modifications.

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