Development and Verification of a Prototype Machine for Polishing Small Volume Cylinder Walls

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Abstract - The present report focuses the development process that was applied to develop a machine which is used for polishing the inner walls of cylinders. The cylinders are for small volume engines which are the major component of lawn mowers. During the design process, creative methods were applied systematically to generate more ideas so that the final decision was optimal selected from them. In the meantime, the problem of shortening the lead time, esp. for novice engineers has been a major issue. In order to overcome the difficulties, the system is functionally decomposed into three major sub-systems so that the development process can be assigned to three persons worked as a team. Or, the sub-systems include the power and transmission, jigs and fixtures, and the feeding mechanism. In addition, commercial CAD and CAE soft-wares, Solidworks® and Pro/Engineer®, were readily utilized to model the ideas in terms of 3D pictures. The 3D models help the personal involved work as an efficient team, esp. in virtually assembling the subsystems. Once the subsystem was independently completed, all parts were then trans- formed into engineering drawings and transferred to machine shop for manufacturing. The assembling was carried out in the lab by students, while all tests, evaluations, and improvements were followed. It has been found that the expected functions, together with the development goal have been met. Meanwhile, the creative design and development process that includes functional decompositions, team cooperation, idea generation and evaluation, and decision making, is successfully adopted.

Keywords – Creative development, a Prototype Machine, Polishing, Design Processes

I. INTRODUCTION

It is quite clear that polishing is normally required for industries of engine cylinders. The process is applied after the inner walls of cyliners have been chromium (Cr) plated. The Cr-plating, or hardening process is mainly for increa-sing the life of cyliners since the relative reciprocating motion of the piston to the wall. Anticipating the increasing labor cost, the key goal of the current development is to develop a automatic, or at least semi-auto machine which will be used to replace the current man-polishing process in the factor located in Canton, China. As the background knowledgement, the facotory has to manufacture 200M cylinders a year to meet the custome's need. Even though the company takes the advantage of low wedge in China, the quality of man-polishing, which is now outsourcing, is the most headache problem of the management. Motivated by this, the company requires the lab in NTUT to develop a polish machine, esp. For 25 and 30 c.c. cylinders, cf. Fig. 1 for detail, that are major products of the company.

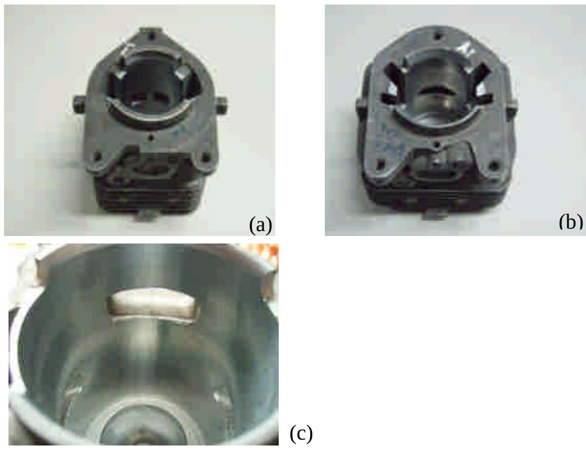


Fig. 1 Cylinders for lawn mowers: (a) 25 c.c., and (b) 30 c.c. before polishing; (c) polished inner wall.

In addition to understanding the polishing process and physical dimensions of cylinders, the present study also started with reviewing the reports concerning design pro-cesses. These included French [1], Pahl & Betiz [2], VDI 2221 [3], etc. However, it seemed to the authors that all these design guidelines are somewhat inadequate. In order to let the development process more systematic, a modified design flow has been set up and shown in Fig. 2. Referring to the figure, this design process has taken into those issues like setting specification, generation of ideas, embodiment of design, and manufacturing, etc. It is thus believed that the design flow, which was modified from [4], is optimal for development of prototype machines.

II. PROBLEMS & NEEDS

A. Problem Analyses

In general, aluminium parts like the cylinder of a lawn mower are made by die-casting. After that, it is then machining, and Cr-plated and polishing at its inner wall. In some cases, it may use *Aℓ-Zn* alloy so the inner wall can be horning directly without plating and polishing. Unfor-tunately, the problem the project facing is not the kind. The present processes are briefly described as follows:

1) Cr-Plating: In order to harden the inner surface of cylinder, normally it is plated with chromium as mentioned earlier. The Cr thickness is between a few μm to 0.1 mm depending on the life specified, while the hardness is 750 ~ 1050 HV [5, 6]. The main reasons to do so are to improve its abilities of (a) anti-abrasion between the piston rings and the wall, (b) anti-corrosion, and (c) to reduce the friction of the two relative motion bodies.

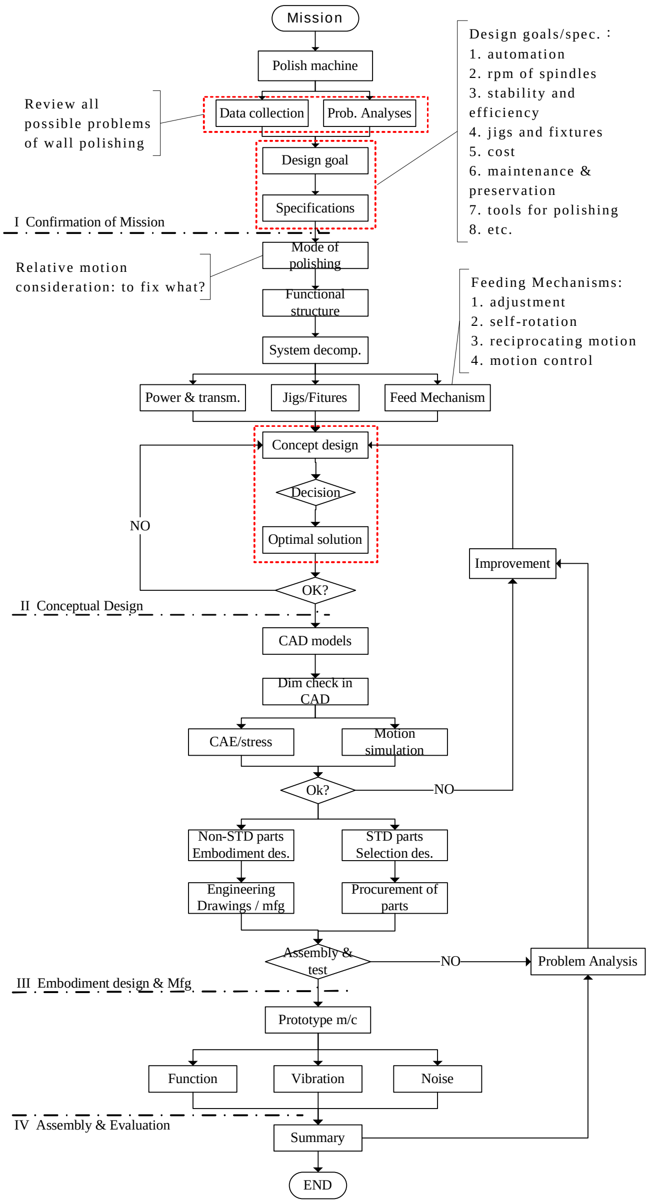


Fig. 2 The development flow of the prototype machine.

2) Polishing: The inner wall "polishing" of cylinders here does not mean "chemical-mechanical polishing", or CMP, which is quite common in industries now-a-day. That is, the traditional mechanical polishing can do the job just fine. As it can be found from handbooks, the linear velocity for polishing can be as high as condition 30 ~ 35 m/s. Too low polishing speed may result in low quality surface. However, on the other hand, too high speed may also result in over-polishing the Cr-thickness.

3) Measurements: The following conditions have to be met after polishing:

- Roundness deviation: ≤ 15 μm
- Straightness: ≤ 10 μm
- Difference in Cr-thickness: ≤ 15 ~ 20 μm
- No fretting is allowed
- Roughness: Prefer to have the surface roughness is somewhere between honing and lapping [7], or Ra ≤ 0.8

B. Goal and Specifications

The goal and specifications are summarized as follows:

1) Automation: Due to mass production and competition considerations, the labor cost has to taken into account in the development of the prototype machine. That is, a semi-automatic one is the minimum requirement.

2) Speed of shafts: To polish the surface of Cr-plated surface, it is found the rpm of tools is ca. 19,000 rpm. However, for the reason of safety, the max. speed of shaft is set to be 12,000 rpm.

3) Stability and Efficiency: Anticipating the stability of the machine, the geometry must be as symmetric as possible. In addition, the min. number of cylinders simultaneously polishing at it is two. Three is preferable.

4) Jigs and Fixtures: The design of jigs and fixtures must be workable for both 25 and 30 c.c., which occupies more than 70% products of the company.

5) Tools of Polishing: Felts, soft cloth or leather may be good materials that are wrapped on the polish rollers. All other chemical polish agents are not preferable. Only mechanical polishing is allowed.

6) Cost: To use standard parts or those can be easily bought from the local market. In addition, it is prefer to have the machine with the min. number of parts so that the latter maintenance can be done in Canton, China.

7) Maintenance and Preservation: Modular structures are preferable so the machine may be sub-assembled in Taiwan then shipped. In addition, the modular replacement can be easier than the whole machine.

III. Creative Design

A. System vs. Sub-systems

Refer to [4], the polish machine development project begins with functional decomposing the machine system. The typical functional structure of the system is shown Fig. 3. In other words, the structural system is decomposed into three main sub-systems. They include the power and transmission, jigs and fixtures, and feeding mechanism sub-systems, cf. Fig. 4 for detail. Once the sub-systems are well-understand, it is possible to organized the team and decide the team members. In addition, the design goal and specification can be thus further objectively examined for all subsystem teams. By doing so, it will be helpful for looking at their structural components.

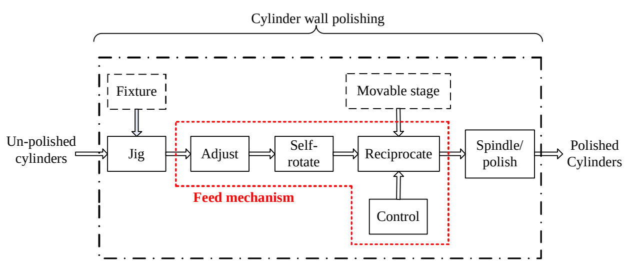


Fig. 3 The functional decomposition of the polish machine.

Once the functional structure is determined, the 3D model is properly constructed following by some hand-sketched pictures of ideas. By examining the dimensions of parts as well as their assembly, one possible to find all possible errors and correct them as early as possible. Meanwhile, the stress analyses are also carried out by a commercial CAE package. This process can ensure the design safety of the components. In addition, the motion and its constraints can also be predicted and verified in terms of this 3D model.

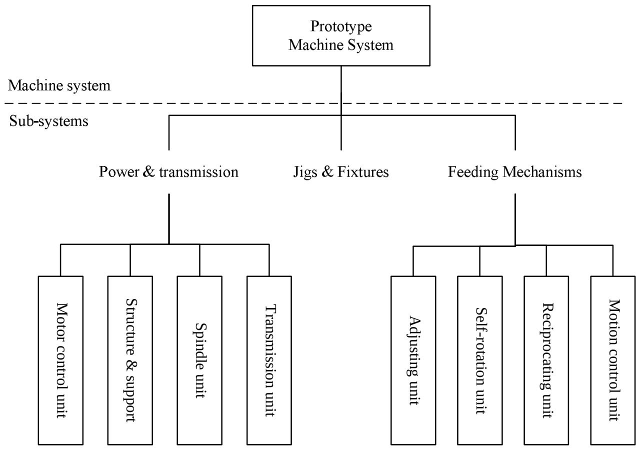
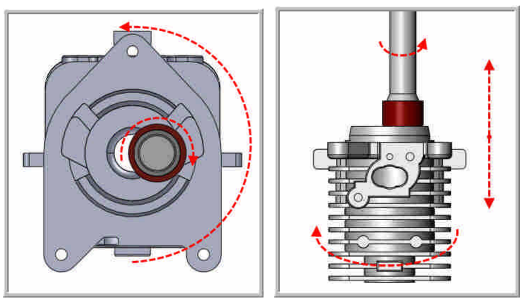


Fig. 4 The structure of sub- and sub-sub-systems of the polish machine.

B. Functional and structural subsystems

As it has been mentioned in the former section, one has decomposed the system by the functions and shown in Fig. 3. While, on the other hand, the corresponding structural system shown in Fig. 4. Furthermore, it is also clear that the polish quality of the prototype machine stems in the mode of polishing. Therefore, by referring this functional decomposition of the system, one is able to generate more ideas as well as the possible optimal design solution. For example, taking into the polish quality into consideration, one is to design a so-called two degree-of-freedom (dof) polishing. That is, the polishing process has to include two dof motions: (a) relative rotational and (b) linear feeding polishing motions. The idea is depicted in Fig. 5. The two polish tools, which is fixed by the spindles, are rotating in high speed, the cylinder itself also slowly turns, shown in Fig. 5(a). On the other hand, the stage where the two cylinders fixed is also simultaneously moving upward until the stage touch the position limit switch.



(a) (b)

Fig. 5 The idea of 2 dof polishing mode: (a) relative rotational; and (b) linearly feeding .

In accordance with the functional decomposition, one is able to general more similar ideas. Refer to Fig. 3, the present study is to design two cylinders in a batch. Following this idea, the two cylinders are manually put them onto the fixtures on the cylinder stage. Once they are correctly fixed onto the fixtures, the 2-dof polishing can be applied.

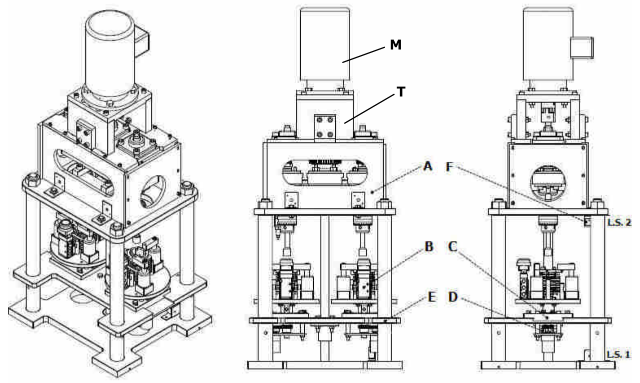


Fig. 6 The complete design idea of the whole prototype machine in its isometric and two side views.

C. Functions of Subsystems

In order to clearly depict the functions of all sub- and sub-sub- systems (cf. Fig. 5), the 3D model of the complete prototype machine is put at Fig. 6. While, on the other hand, the detail design solutions of sub-systems are described in the following:

1) Power and Transmission subsystem: The subsystem that provides the main power to the whole machine is motor, marked by A in Fig. 5 [8]. In order to provide the high rpm, the transmission unit, marked by T, as well as the corresponding structure so the whole power and transmission assembly can be firmly mounted on the machine frame. The subsystem includes four units: motor and its control, high speed rotational spindles, transmission and structural frame units.

2) Jigs and Fixtures subsystems: To provide the positioning and fixing, this subsystem also the key component that providing the exchange function for two volume sizes of cylinders. Refer to mark B in Fig. 6.

3) Feeding Mechanisms subsystem: The main functions of this subsystem are providing self-rotational and reciprocating motions, and linear feeding. Refer to mark C in Fig. 6. It also includes four sub-sub- systems. They are adjusting, motion control, and self-rotation and reciprocating units.

D. Designs of Subsystems

1) Power and Transmission subsystem: The main driving power is AC motor. Together with the motor control unit, which is rigidly supported by it frame box. All transmission and gears are installed inside the box. There are four units in this subsystem:

- **Motor and its Control Unit:** The AC motor is 3-phase, 220 v and 1/2 HP. All parts of this control unit are , standard, local made and can be easily procured in the local market.
- **Box Frame Unit:** In order to simplify the structure of the transmission box, the box is made of steel plates (cf. Fig. 7a) and firmly bolted in this prototype machine. However, the design of the box may be easily replaced by cast iron if necessary. Notice also that the hand-holes have been

properly designed for dismantling, assembling and installation. In addition, stress and dynamic analyses using a commercial CAE package (COSMOS/ Design STAR [9]) is also performed.

● **Spindle Shaft Unit:** There are three transmission axles in the machine, cf. Fig. 7(b). All collars, key-ways, set-screws are all properly designed and CAE analyzed. The timing belts are used for the transmission belts.

● **Speed Variable Unit:** Two constant speeds are designed in the prototype machine. The changes of the speeds are accomplished by replacing the belt gears. However, it can be replaced by a shift handle if the cost can be compromised.

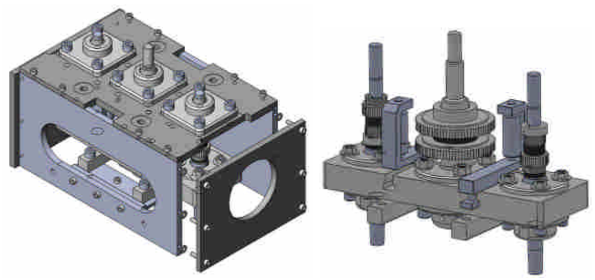


Fig. 7 Transmission unit: (a) Transmission box, and (b) The layout of spindle unit.

2) Jigs and Fixtures Subsystem: In accordance with the design goal, the machine must be workable for both 25 and 30 c.c. cylinders. This need can be only accomplished by the fixture design with quick change mechanism. Adopting the concept of fixture commonly used in automatic machines, one has decided using pneumatic power for the positioning power which is based on the low cost consideration.

Applying the idea to the CAD model, it is shown in Fig. 8 for detail. The picture shows the assembling procedures. The 3D picture like this can be very helpful in the team work since it clearly provides visual manual so that all team members can follow correctly. Under this situation, the key designer needs not to waste the time to communicate again and again with other team members.

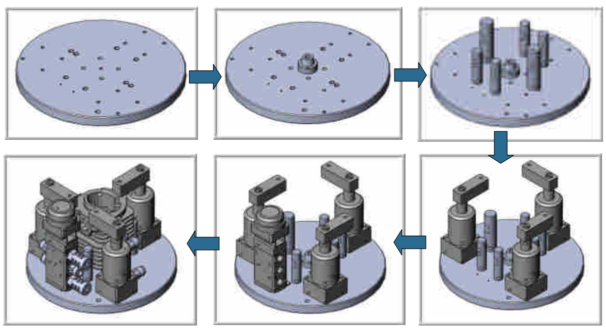


Fig. 8 The typical 3D assembling manual for the fixtures.

Applying the pneumatic power, the airflow can be a crucial problem since the need of hoses for pressured air. The supplied air from a compressor is directed to an air regular valve before it is sent to the air swing clamp cylinders. In addition, a muffler is installed to reduce the blowing noise. Refer to Fig. 9 for the layout of the airflow.

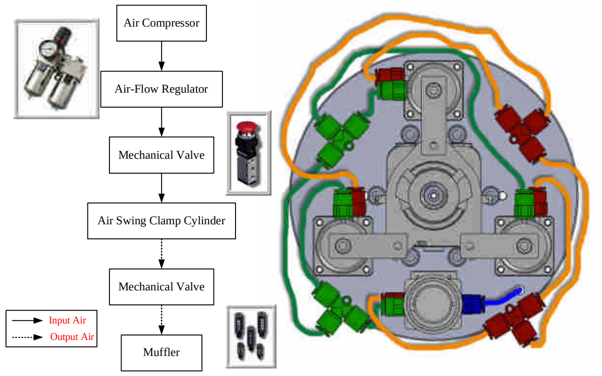


Fig. 9 The Layout idea for the pneumatic clamp.

3) Feeding Mechanisms subsystem: There are four units in this subsystem, cf. Fig. 4. Anticipating the thickness of Cr-plating may varied from quite a wide range, a mechanism that allows the polish tools slightly and manually adjusted is designed. This function is accomplished by 10 mm slotted holes. That is the tools are movable within max. 10 mm. Except the motion control unit, other three units are detail introduced as follows:

● **Self-rotation Unit:** In addition to the tunable tools on spindles, the cylinder itself turns slowly when it is in the polishing process. The idea to carry out this self-rotating motion is that the whole cylinder fixture turns as it is being polished. However, the pneumatic flow is used in the clamp, a rotating joint valve is necessary. Besides, a small dc power (dc 12 v, 1.6 W) is selected for the driving power. The 3D model is shown in Fig. 10 for detail. The specifications of this dc motor are: starting torque 0.6 kg-cm, and max. rotation 100 rpm.

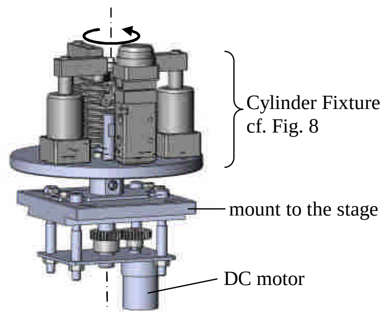


Fig. 10 The 3D model of the self-rotating unit.

● **Reciprocating Unit:** The total weight including the motor and transmission is ca. 60 kg_w. Thus, it is may not reasonable to have the whole power unit moves up and down so that the whole depth of the inner wall can be completely polished. Instead, one is to design a movable stage. On this stage, there are mounted with a self-rotating unit, cylinder fixtures and other related mechanisms. This reciprocating unit is driven by a ball-screw, which is believed to be lowest cost and easy to install. In addition, there exist four guide rods to confine the motion in an accurate linear one. Two position limit switches are set at the top and bottom of one guide rod. These limit switches are used to protect the stage not to have undesired motion or over strokes. The detail idea in terms of a 3D model is shown in Fig. 11.

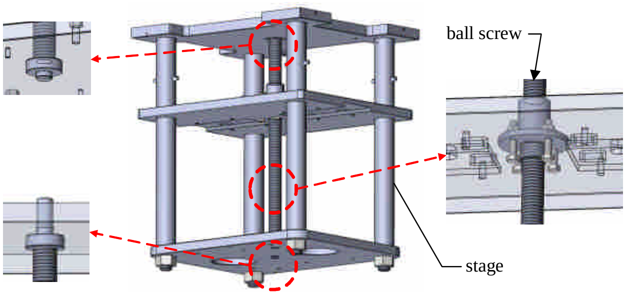


Fig. 11 The 3D model of the reciprocating unit.

● **Stage Position Control Unit:** The up and down motion of the stage is controlled by two limit switches, refer to Fig. 12(a). Operating in manual mode and pushing UP button, the stage will accordingly move upward until the stage hits LS2. On the other hand, if button DN is pressed, the stage will similarly goes down until LS1 is reached. On the other hand, in case of automatic mode, the stage will reset to the lowest bottom then move upward until it reaches LS2. One may refer to Fig. 12(b) for information.

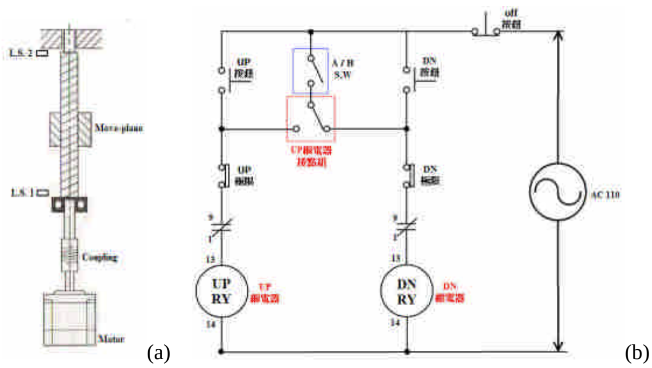


Fig. 12 The stage position control unit: (a) locations of LS and (b) their layout circuit.

IV. *ASSEMBLY AND EVALUATIONS*

A. Assembling of the Complete Machine

Putting all standard parts that were purchased from the local market and the out-sourcing parts together, one starts assembly the complete machine. Unlike the traditional way in which the engineering drawings are used as the assembling guide, 3D model drawings similar to Fig. 8 are used. The subsystems were assembled and simple tests were performed prior to place them onto the whole machine. Fig. 13 show the subsystem of the pneumatic clamp which is used as the fixture in the prototype machine. Readers may compare the picture with Fig. 8.

Fig. 13 The assembled pneumatic clamp.

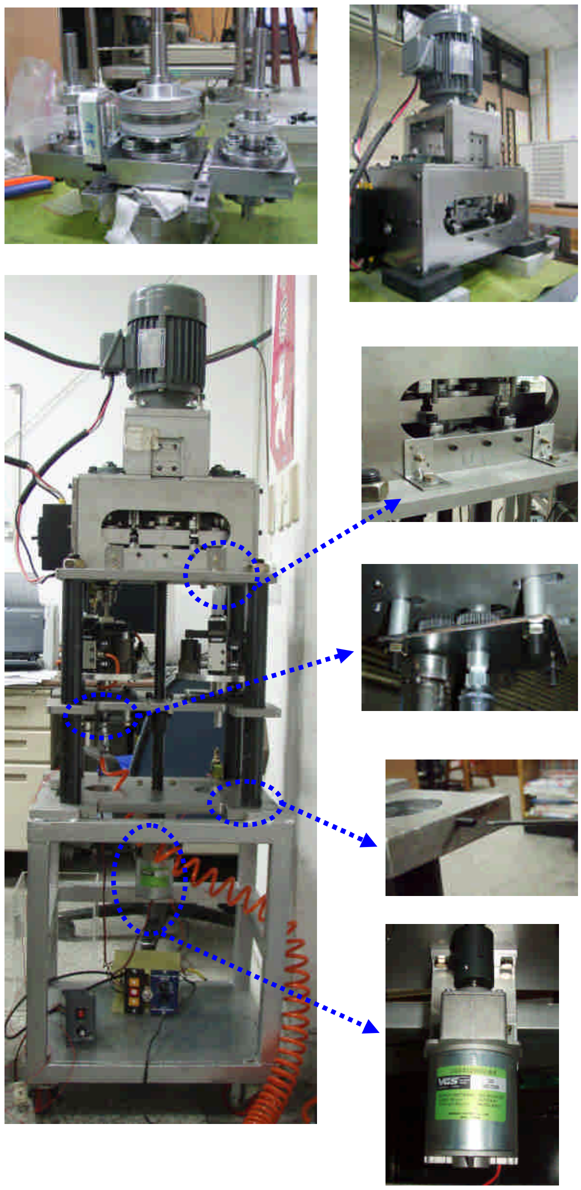


Fig. 14 The assembled prototype polishing machine.

Once the assemblies of subsystems are complete, one starts to assembly the whole machine. Fig. 14 shows the snap shot of machine assembly.

B. Tests and Evaluations

After the complete prototype machine is assembled, dry-run tests were issued. In addition to the dry-run tests, more than eleven (11) items of evaluations [10] were also performed along with the tests. Those 11 evaluations mostly focused at the design functions, to install and dismantle of tools, checks in lubrication, electric and pneumatic systems and so on. It has discovered that there exists air leakage at the rotating joints of clamps. Since those joints were directly purchased from the local market, the present design just bought new ones and replaced them. Or, the air leak does not create unsolvable problems in the prototype. However, it has also found that the design for changing speeds is quite difficult inconvenient. This is recommended for an improve design in the next generation.

In addition to dry-runs and function evaluations mentioned, the temperature rise, vibration and noise of the machine have been checked. The latter two are described in the following sections.

A. Vibration Measurements

The three locations were determined to measure the vibrations and marked A, B and C in Fig. 15. The vibrations are acquired by their accelerations under the speed of spindle is at ca. 7980 rpm. The measured results are depicted in Fig. 16.

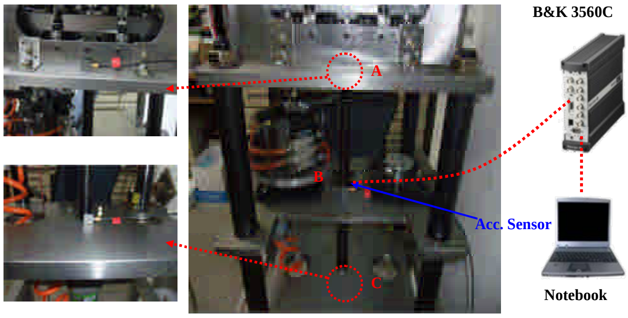


Fig. 15 The accelerometer locations.

As it can be seen from Fig. 16 that there exist three harmonic peaks at 1X or 133 Hz (7980 rpm) and 2X (266 Hz). This is understand that the reason stems at the driving axles. More importantly, the amplitudes of vibration are acceptable and within ISO 10816 [11].

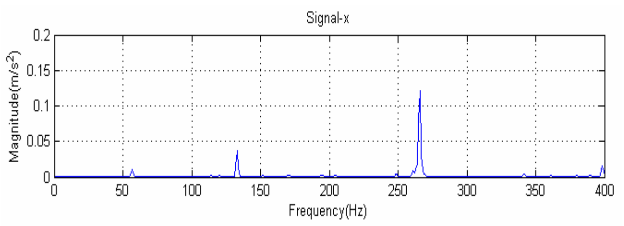


Fig. 16 A typical vibration measurement (location A_x).

B. Noise Measurements

Similar to the vibration measurement, the noise levels were also recorded and the set-up is shown in Fig. 17. The microphones were placed 5 to 10 mm away and pointed to the locations to be measured. It was found that the max. noise locates at the transmission box (82dB) with frequency ranged at 1 to 4 kHz, and the belt (92.6 dB) with 8 kHz. However, the these noise levels can group as a good level from the standard of machine tools.

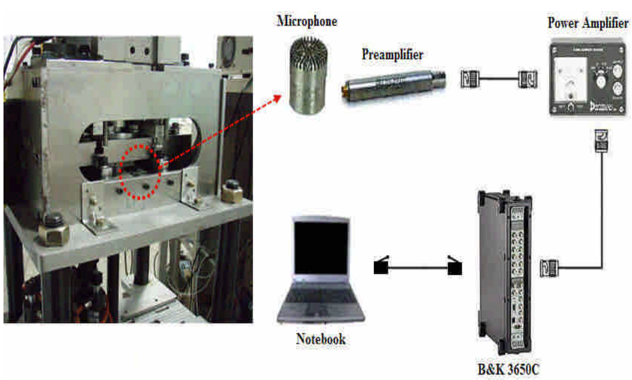


Fig. 17 The set-up of noise measurements.

V. CONLUDING REMARKS

The prototype machine for polishing the inner wall of cylinders that are used for small volume lawn mowers has been developed in accordance with the customer's need. During the developing process, the customer's need and problems had been well understand and analyzed before the design proceeded. Meanwhile, a creative design process has been systematically adopted by functionally decomposed the machine into three main subsystems. And, the subsystems were independently taken care by the team members in the lab. In addition, the interfaces of subsystems were linked by using CAD models, which have widely and properly applied through the whole design and assembly processes.

The prototype polish machine was dry-run tested and functionally evaluated after it has been assembled in lab. More than 11 items of checks have been carried out, while the temperature rise, vibration and noise levels were recorded for analysis purposes. All checks in requirement of functions and measurements have substantiated that the developed prototype machine can be regarded as in a good level, in accordance with ISO and related standards.

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