An Arrangement and Performance Analytics of Elements of Vibration Testing Machine for Taper Roller Bearing

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Abstract: The paper addresses the need for automation in production line. A detailed evaluation of various components required for converting a manual bearing vibration testing machine to an automatic one is carried out. Function and Description of each component is studied. The components include conveyor belts, laser Doppler vibro meter, pneumatic system, mechanical probe, timing and control sensors, speed control system, data analysis and storage unit. A method of selecting each component for automatic vibration testing machine is offered. Based on the structure of automated machine the initial set of alternate variants is defined and a formal model of automatic vibration testing machine is developed. Design of conveyor belt, linear drives, pneumatic system, isolation pad, PLC and HMI system is discussed below. Analysis of supporting structure of Vibration Testing Machine is done using ANSYS 18.1 and results are shown.

1. Introduction

The MVU 150A is capable to measure the bearing described above (except HUB-units) and even more. Additional to the standard axial loading unit, it can be equipped with a radial loading unit. For that also cylindrical roller bearings can be tested. The MVU works with vertical high-precision hydrodynamic testing spindle. The driving unit is mechanically separated from the machine frame for an optimum vibration isolation. The thrust test loads and the radial test loads are applied by using the pneumatic loading unit. The evaluation of the noise and the vibrations and the corresponding classification of the test pieces are also carried out via the measuring electronics. Normally the three standard frequency bands are measured, within these bands the tolerance limits are freely programmable and/or are available after calling the appropriate bearing type. Evaluation criteria according to customers’ requirements are possible. Frequency spectrum and detailed analysis of the spectrum is also used to go into depth with the locations and causes of the bearing vibrations. The applicable measurement outcomes are documented and also statistically compressed via a printer. The
machine can also be connected to larger and prominent computer systems, e.g., to introduce the noise test in the company's quality assurance systems.

2. DESIGN OF THE MACHINE COMPONENTS

2.1. Design of Linear Drive:

2.1.1. Selection of Piston Diameter:
- Work piece load = 3.72 kg
- Stroke length = 372.5 mm
- Force \( F = m \times g = 3.72 \times 9.81 = 36.49 \) N
- From FESTO Catalogue:
  - Considering piston diameter of 32 mm.
  - Moving mass = 4042 g = 4.042 kg
  - Theoretical force at 6 bar, advancing = 483 N
  - 50% of theoretical force = 241.5 N
  - Static holding force with 32 mm piston = 500 N
- As the force of bearing is less than the 50% theoretical force selecting piston of = 32mm.

2.1.2. Pusher
- Design parameters needed for selection:
  - Stroke length = 372.5 mm
  - Bearing weight = 3.72 kg
  - Selection of desired linear drive from FESTO catalogue
  - Designation: DFM32-B-400-P-A-G

2.1.3 Positioner
- Design parameters needed for selection:
  - Stroke length = 74 mm
  - Bearing weight = 3.72 kg
  - Selection of desired linear drive from FESTO catalogue
  - Designation: DFM25-B-100-P-A-GF

2.1.4 Push-out
Design parameters needed for selection:
- Stroke length = 372.5mm
- Bearing weight = 3.72kg
- Selection of desired linear drive from FESTO catalogue
- Designation: DNC32-300-Q-PPV-A

3. Bending Strength of holding structure for Loading Cylinder:

![Figure 1. CAD Model of Vibration Testing Machine](image)
W = 143 * 9.81 = 1402.83 N

L = 245 mm

Y = (441/2) = 220.5 mm

\[ I = \frac{bd^3}{12} = \frac{245 \times 441^3}{12} = 1751.0583 \times 10^6 \text{ mm}^4 \]

Bending Moment, \( M = \frac{W \times L}{2} = 1402.83 \times (245/2) = 171846.675 \text{ N/mm} \)

Now by Flexure Formula,

\[ \frac{M}{T} = \frac{\sigma}{\gamma} \]

\[ \frac{171846.675}{1751.0563} = \frac{\sigma}{220.5} \]

\[ \sigma = 0.021639 \text{ N/mm}^2 \]

Since bending moment is so small, there will not be effect on machine component failure due to bending of supporting structure.

4. CATIA Model:

![CATIA Model of Vibration Testing Machine](image-url)
Table 1: Properties of Hydraulic Oil

| Typical Properties:                          |       |
|---------------------------------------------|-------|
| Density, g.cm\(^{-3}\) @ 15.5°C             | 0.860 |
| Flash Point                                 | 205°C |
| Pour Point                                  | -30°C |
| Viscosity                                   |       |
| Kinematic, 40°C                             | 32 cSt|
| Kinematic, 100°C                            | 5.4 cSt|
| Viscosity Index                             | 100   |

5. PLC and HMI of the Machine

The MVU Machine is operated with the help of PLC (Programmable Logic Controller) and HMI (Human Machine Interface).

5.1 SIMATIC S7-1500

The PLC used is of Siemens having designation SIMATIC S7-1500. The SIMATIC S7-1500 is an advanced controller that convince the user with their ultimate power, which provides high level of performance for medium-sized to high-end machines with high demands on performance, communication, flexibility, and technology functions. The SIMATIC S7-1500 efficiently increases performance with a fast backplane bus, PROFINET interface, and with shortest reaction times.

Figure 3. SIMATIC S7-1500
1. SIMATIC HMI TP-700 COMFORT
The HMI is human machine interface used for the exchange of data between machine and programmable Logic Controller. SIMATIC HMI TP700 Comfort has a Comfort Panel, Touch operation, 7” widescreen TFT display, 16 million colors, PROFINET interface, MPI/PROFIBUS DP interface, 12 MB configuration memory, Windows CE 6.0, configurable from WinCC Comfort V11, which makes it the reliable interface.

2. Statement List:
Statement List (STL) is a very basic programming language that can produce the code section of logic blocks in a PLC program. Its syntax for statements is analogous to compiler language and consists of programs followed by addresses on which the instructions work.

The Programming Language STL: Amongst all of the programming languages with which a user can program S7 controllers, Statement list language is the nearest to the machine code MC7 of the S7 CPU, thus by using it to program S7 controllers, you can optimize the run time and the use of memory. The programming language STL has all the necessary elements for creating an optimum user program. It contains a comprehensive range of programming instructions. Overall 130 different basic instructions and a wide range of addresses are available and can be effectively utilize. Functions and function blocks allow you to structure your STL program efficiently.

The Programming Package: The STL programming language is an integral part of the STEP 7 Standard Software. This means that following the installation of your STEP 7 software, all the editor functions, compiler functions and test/debug functions for STL are made available for user.

6. PLC Ladder Diagram
Ladder diagrams are schematic diagrams which are commonly used to document industrial control logic systems in a specialized manner. They are called "ladder" diagrams because they resemble a ladder like structure, with two vertical lines (supply power) and as many "rungs" (horizontal lines) as there are control circuits to represent.

![Ladder Circuit for control ON enable](image)

**Figure 4.** Ladder Circuit for control ON enable
7. **Inductive Proximity sensor**

Benefits of using the inductive proximity sensor for machine operations:
1. Maximum durability with non-contact, maintenance free technology and high environmental protection.
2. Flexibility due to a wide range of functions and programmable measuring and switching range.
3. A variety of housing styles: from compact designs for machine tools (14 mm measurement length) to designs for heavy machinery (960 mm measurement length).
4. High noise immunity ensures process reliability.
5. Increased efficiency with measuring and switching functions in one device.

7.1 **Simulation of Vibration Testing Machine**

![Image of Vibration Testing Machine Simulation]
Figure 7. Meshing of Machine Model

Properties:

Table 2. Properties of Material

| Property                                      | Value                           |
|-----------------------------------------------|---------------------------------|
| Density                                       | 7850 kg m^-3                   |
| Isotropic Secant Coefficient of Thermal Expansion | 1.2e-005 C^-1                  |
| Specific Heat                                 | 434 J kg^-1 C^-1               |
| Isotropic Thermal Conductivity                | 60.5 W m^-1 C^-1               |
| Isotropic Resistivity                         | 1.7e-007 ohm m                 |

Table 3. List of Defined Loads

| Object Name | Fixed Support | Force | Moment |
|-------------|---------------|-------|--------|
| State       | Fully Defined |       |        |
| Scope       |               |       |        |
| Scoping Method |             |       |        |
| Geometry    | 1 Face        | 2 Faces |        |
| Definition  |               |       |        |
| Type        | Fixed Support |       |        |
| Suppressed  | No            |       |        |
| Define By   | Components    |       |        |
| Coordinate System | Global Coordinate System | |
8. Total Deformation:

![Figure 8. Total Deformation](image)

Table 4. Solution of Total Deformation

| Time [s] | Minimum [m]    | Maximum [m] |
|----------|---------------|-------------|
| 1.       | 0.            | 3.4436e-005 |

8.1 Equivalent Stresses:

![Figure 9. Equivalent Stresses](image)
Table 5. Solution of Equivalent Stresses

| Time [s] | Minimum [Pa] | Maximum [Pa] |
|----------|--------------|--------------|
| 1.       | 51.117       | 1.1006e+007  |

8.2 Directional Deformation:

![Directional Deformation Image]

Figure 10. Directional Deformation

Table 6. Solution of Directional Deformation

| Time [s] | Minimum [m] | Maximum [m] |
|----------|-------------|-------------|
| 1.       | -3.3787e-006 | 3.543e-006  |

9. Conclusion

The Automated Vibration Testing Machine gives better performance in terms of accuracy, speed and testing time. The minimum human interference is achieved through installation of conveyor belt system, laser vibrometer, proximity sensor, and PLC and HMI systems. Also the operational maintenance of machine is simple and economical. The machine operator is eliminated as line operator can easily handle vibration testing machine. The overall production time of Taper Roller Bearing is reduced to optimum limit. The cycle time of machine is reduced effectively with greater efficiency of machine. The lead time and setup time of machine is reduced considerably. As the operator interference is reduced the accuracy is increased. Overall machine cost is reduced as we have modified on certain parts of machine.

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