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Original Article

Automated Servo Controlled Brake Booster Characteristics Verification Test Rig Development

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Abstract *- The development of an automated servo-controlled brake booster characteristics verification test rig for testing and measuring the parameters of the Brake booster, Tandem Master Cylinder and Brake booster with the tandem master at various vacuum conditions. The existing brake booster performance test rig is manually operated, has an uncontrolled feed rate due to the air cylinder used as an actuation system, less accuracy sensors are used, and the testing lead time is high. Boosters' return time to test is measured by a stopwatch; its measurement values varied based on person to person. By the existing test rig is able to measure the test parameters only for brake boosters. The focus of this project is to develop a rigged model based on the requirements of brake booster product specifications, simulate the brake booster mounting fixture with various boundary conditions and fabrication of fixture with the selection of a suitable servo mechanism. To achieve an accurate travel ramp rate, a servo motor with an inbuilt servo drive programming unit will be incorporated. Measurement system analysis will be taken to verify the data capturing of the newly developed test rig.*

Keywords *- Test rig, FEA Analysis, Fixture development, Booster, ANSYS, LabVIEW.*

1. Introduction

The conversion of kinetic energy into heat energy is a function of the frictional force generated by the frictional contact between brake shoes and the moving drum or disc of a braking system. The working of a Hydraulic barking system is based on Pascal's law.

In the hydraulic system, the brake force is applied by the driver on the brake pedal. Here, the input load is converted into hydraulic pressure by the master cylinder then this hydraulic pressure from the master cylinder is transferred to the final brake drum or disc rotor through brake lines. Brake fluid is used in hydraulic brakes for the transmission of brake pedal force to stop, or de accelerates the vehicle. When the brake pedal is pressed, the high-pressure fluid from the master cylinder pushes the piston outward. The piston pushes the brake pad against the rotating disc. As the inner brake pad touches the rotor, the fluid pressure exerts further force, and the caliper moves inward and pulls the outward brake pad towards the rotating disc, which touches the disc. Now both the brake pads are pushing the rotating disc, a large amount of friction is generated in between the pads and the rotating disc and slows down the vehicle and finally lets it stop. When the brake pad is released, the piston moves inward; the brake pad moves away from the rotating disc. And the vehicle again starts to move. Brake boosters provide power assistance to the operator, during the brake application, in a hydraulic braking system, by boosting up input mechanical effort applied at the brake pedal using a vacuum. In the absence of a vacuum, the brake booster directly transfers the input effort to the hydraulic braking system.

In this project, validate the brake booster and master cylinder as part level. For that new test, the rig is planned to develop without existing known issues.

2. Methodology

The purpose of a literature review is to gain an understanding of the existing research and debates relevant to a topic or area of study and to present that knowledge in the form of a written report. Conducting a literature review helps us build our knowledge in our field.

Based on the product specification and customer requirements brake booster testing fixture will be designed. A Servo motor with a control mechanism, and sensors for measuring load, travel and pressure will be selected. The fixture will be subjected to various boundary conditions with respect to load. Finalize fixture design for fabrication. These are the methodologies for the project. Use Model-Based Design with CREO software and ANSYS for FEA analysis.

New load cells with high accuracy and STS pressure sensors are planned to incorporate into the test fixture for more accuracy.

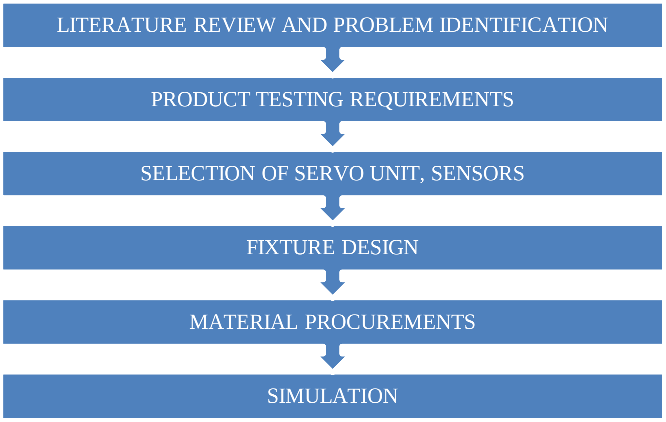


Fig. 1 Methodology flow chart

2.1. Existing System

In the existing system, a list of performance tests can be carried out.

- Leak test at ambient condition
- Input load Vs Output load Characteristics
- Return time test
- Breakage test

Problems identified from the existing systems are as follows:

From this above list of performance tests, one of the tests, i.e., the Piston Return Time test, can be tested through manual measurements. No graphical data is available for the Piston Return time test.

Input Travel ramp rate not achieved by the existing air cylinder actuating system. Unable to achieve the exact ramp rate as per standard. Test sequence operation and data acquisition program has been developed in the NI lab view system. The dedicated motion controller is not available in this system. Therefore, the set point of load, pressure, and travel reference values are not reached with respect to the set travel ramp rate.

Existing syscon make Load cell sensor accuracy value is 0.25% and capable of 100 samples per second can be measured. Therefore, the accuracy of test data measurement is reduced. Existing Test ramp rate results are not in controlled value.

By the existing test rig is able to measure the test parameters only for brake booster alone with less accuracy.

- Controlled feed rate is not available now.
- Automated testing is not available.
- Additional requirements mentioned by the latest customer specifications are unavailable (for ex, cut-off travel, Booster + TMC combined tests, and travel-related tests).

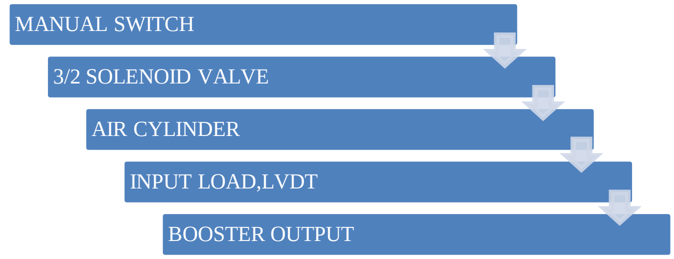


Fig. 2 Block diagram – Existing system

2.2. Proposed System

In this project, a servo-controlled actuation system with a lead screw mechanism is planned to achieve the controlled ramp rate and return time test setup incorporated with the fixture mechanism to operate to avoid manual measurement—selection of pressure sensors and linear potentiometers for data acquisition. A new HBM makes load cell was planned to procure and incorporate into the test fixture for more accuracy. Hence the number of sampling data measurements can be increased. Configuration of digital I/O's, analog input signals and output signals in NI lab View program. Selection of servo motor with inbuilt motion control drive unit for installation in an existing test rig to achieve the travel ramp rate.

3. Analysis

3.1. Design Calculation

3.1.1. Design of Brake Booster Fixture

Fixture design depends on the below parameters:

- Brake booster input and output load
- Servo motor input load

3.1.2. Brake Booster Input and Output Load

Brake booster input and output load (taken from product drawing)

Brake booster input load = 2500 N

Booster ratio = 6.7

Vacuum = 600 mmHg

Booster output load = 7850 N

For TMC input load:

TMC die = 28.57 mm

TMC area = π/4*28.57*28.57

= 640.75 mm2

Max delivery pressure = 140 bar

Required input load = 8970.5 N

Servo motor selection was made based on the booster testing requirements

Fig. 3 Servo motor

A servo motor is a rotary actuator that allows for precise control of angular position. It consists of a motor coupled to a sensor for position feedback. It also requires a servo drive to complete the system. The drive uses the feedback sensor to control the rotary position of the motor precisely.

3.1.3. Calculation of Servo Motor with Gearbox Output Ramp Rate

Table 1. Calculation of ramp rate

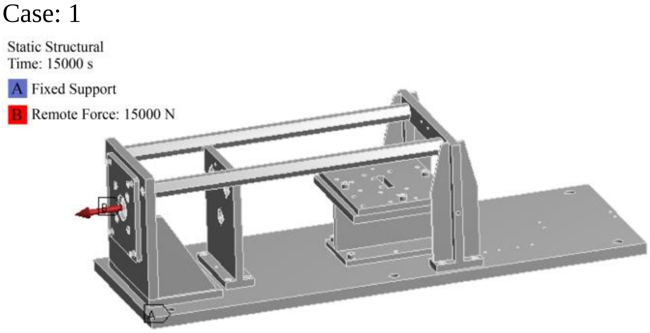
Parameters	**Unit**
Servo motor-rated speed	4000 RPM
Gearbox ratio	5
Gearbox output speed	800 RPM/13.33RPS
Ball screw pitch	5mm
Max travel per second	66.66mm

3.2. FEA Analysis

Based on the product specification, the fixture design has arrived, and the fixture model has been generated by CREO software.

Boundary Conditions:

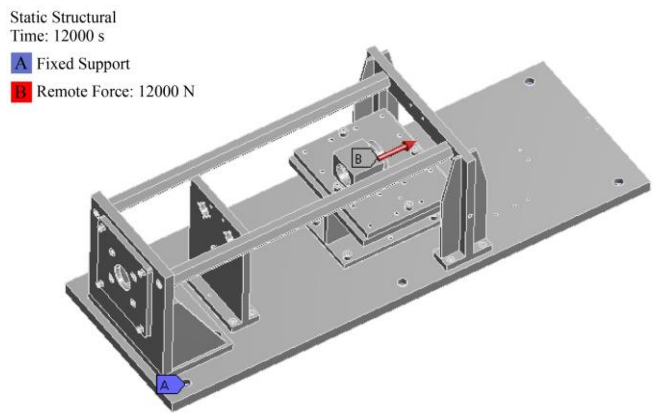
Case: 1



Summary:

1) 15000N is applied at the Booster mounting plate.
2) [The input force applied by the servo motor to check VBV performance is 2500N, but due to air pressure and diaphragm, the load is multiplied up to a max of 15000N. Therefore, 15000N is applied]
3) Fixed support is given at the base rivet holes.

Case: 2



Summary:

1) 12000N is applied at the Bearing rivet holes
2) [The max. load of the servo motor is 12000N. Therefore, 12000N is applied at the Lead screw nut lock; in this case, there will be a vacuum inside VBV]
3) Fixed support is given at the base rivet holes.

CASE 1-Stress Results

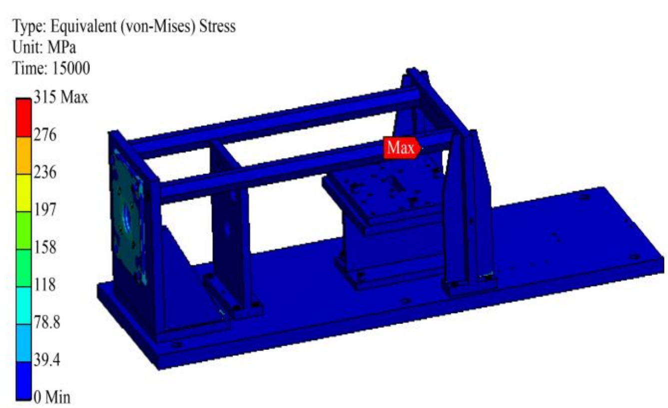
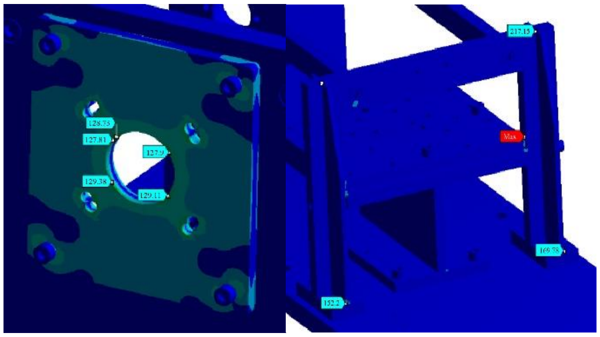


Fig. 4 CASE 1-Stress results



Summary:

1) The max. equivalent vonMises stress (315 MPa) is induced in the weld region
2) The vonMises stress induced in the Booster mounting plate is 129MPa, which is below Mild Steel yield strength 370MPa.

CASE 1-Deformation Results

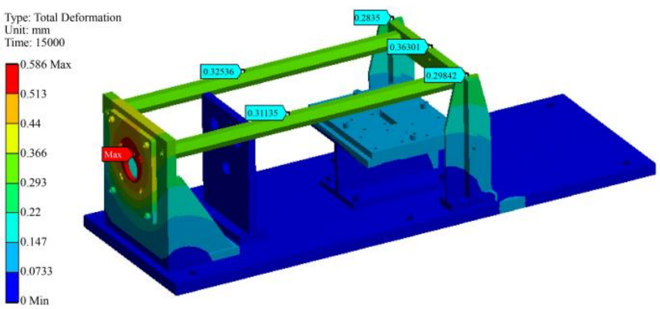
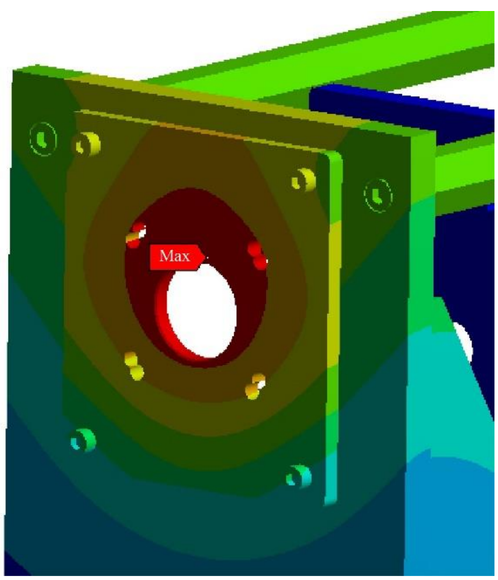


Fig. 5 CASE 1- Deformation results



The max. total deformation of 0.586mm is noted in the Booster mounting plate at 15000N

CASE 2-Stress Results

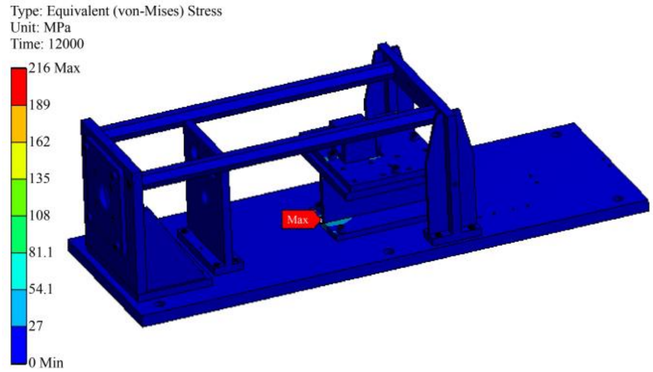
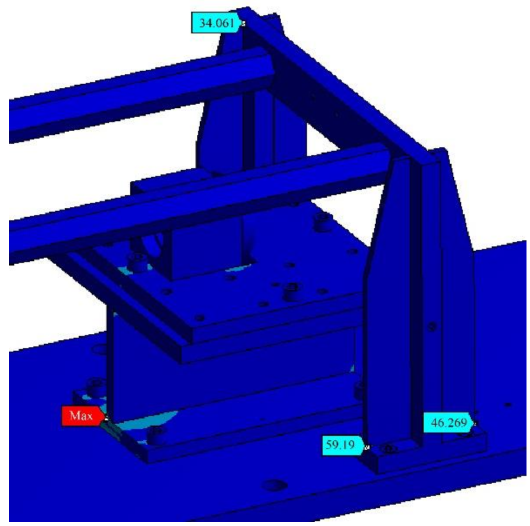


Fig. 6 CASE 2- Stress results



The max. equivalent vonMises stress(216 MPa) is induced in the weld region.

The vonMises stress induced is less than Mild Steel yield strength 370MPa.

CASE 2-Deformation results

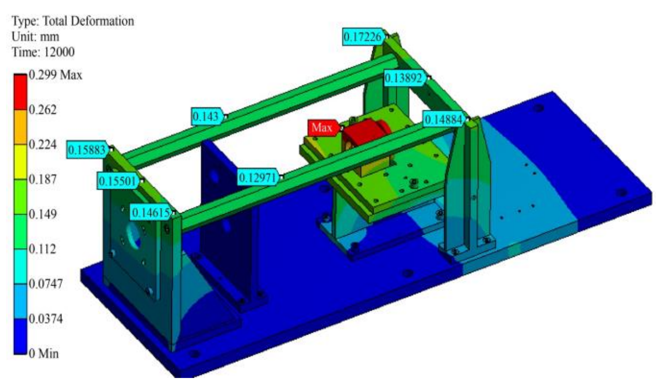
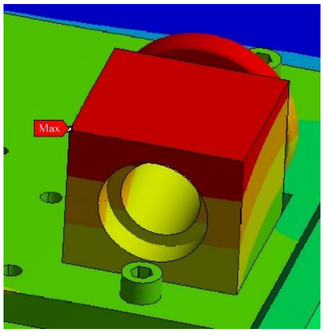


Fig. 7 CASE 2- Deformation results



The max. total deformation of 0.299mm is noted in the Lead screw nut block at 12000N.

4. Results

It is observed that the induced vonMises stresses in both cases are less than the Mild Steel yield limit (370 MPa).

The deformation observed is 0.586mm and 0.299mm for case 1&2, respectively.

Table 2. Simulation results

Cases	Load (N)	Max. vonMises Stress (MPa)	Allowable stress (Mpa)	Factor of safety (FOS)	Deformation (mm)	Remarks
Case1	15000	315	370	1.17	0.586	Safe
Case2	12000	216	370	1.71	0.299	Safe

5. Conclusion

In this project, the testing requirement of the brake booster, tandem master cylinder and VTMC were identified with various customer requirements as well as JASO standards. The brake booster test fixture's design, modeling, and simulation were completed successfully. The Sensors, Servo motor and gearbox selection were completed, and procurements are in progress.

Future work

Proving the proto-model development, testing is the only way of approach. So below works are planned for the next phase of the project.

- Fabrication of brake booster test fixture.
- NI program will be generated with respect to brake booster testing requirements.
- Hardware and software will be integrated for data logging and communication through the NI program with the servo drive system.
- Followed by it, a measurement system analysis will be made for the developed brake booster test rig.
- The test will be conducted with respect to brake booster specifications.
- Test results are analyzed and concluded.

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