EC Hydraulic Drive Cylinder Load Test

John Wu

May 13, 1991

DØ Engineering Note 3740.510-EN-310

Approved: _____ **Date:** 5/30/91

EC Drive Cylinder Load Test

5/13/91
John Wu

Overview:

This engineering note documents the testing of the EC hydraulic drive cylinder. The test was done to insure that the cylinder could operate at the desired compression. The purpose of the test was to determine the deflection of the cylinder rod at a pressure of 7000 psi. This note includes an explanation of the procedure used and a summary of the result of the testing done on May 1, 1991 by Gary Trotter.

Cylinder Design Considerations:

Engineering note 3740.520-EN-254 describes the cylinder and its purpose. The purpose for load testing the cylinder was to insure that it could operate at the pressures required. These pressures were calculated in EN 254, with the appropriate safety factors included. Another engineering note to refer to is note 3740.510-EN-298, which explains the testing of the cylinder relief valve, and the effect of the difference in cross-sectional areas on the forces involved. The general result of this load test was that the cylinder could operate safely at the design pressures.

Maximum Test Pressure:

Since the rod was tested in compression, calculations were required in order to determine the buckling force of the rod. The maximum cylinder test pressure was based on the allowable force on the rod for elastic buckling. This force was calculated using two methods, a simple Euler column calculation, and an AISC method.

Euler Column Calculation:

ref: Mechanical Engineering Design

Section 3-10, p. 116 - Theory of Columns

P_{cr} is the critical buckling load at which the rod will fail.

$$P_{cr} = \frac{n\pi^2 EI}{L^2}$$

The rod was pinned at one end, and the other end was free to move inside the cylinder, so it was assumed that these were simple supports. For rounded-rounded end conditions,

$$n_{theoretical} = n_{conservative} = 1$$

L = (stroke length of 41") + (length of rod cap MB-294751)

= 41" + 3-1/16"

= 44.0625"

The rod material is C1045 cold drawn steel, so Young's modulus is

$$E = 30 \times 10^6 \text{ psi}$$

The rod has a 1-1/2" diameter, so

$$R = 0.75"$$

And the moment of inertia for a circle cross-section is

$$I = \frac{\pi R^4}{4} = \frac{\pi(0.75")^4}{4} = 0.2485 \text{ in}^4$$

Therefore, the critical buckling load for this Euler column is

$$P_{cr} = \frac{(1)\pi^2(30 \times 10^6 \text{ psi})(0.2485 \text{ in}^4)}{(44.0625 \text{ in})^2} = 37{,}897 \text{ lbs.}$$

This corresponds to an oil pressure of

$$\frac{37{,}897 \text{ lbs.}}{\frac{\pi(2 \text{ in})^2}{4}} = 12{,}063 \text{ psi}$$

The calculated force is well above the actual test force. At a test pressure of 7000 psi, the test force is approximately 22,000 lbs. Therefore, the rod will not fail according to Euler column calculations.

AISC Calculation:

ref: Manual of Steel Construction, AISC

Section 1.5.1.3, p. 5-19 - Compression

Compare $\frac{KL}{r}$ and C_c (slenderness ratio) to choose equation.

Table C1.8.1, p. 5-124

Assuming two pin connections (simply-supported),

$K_{theoretical} = K_{recommended} = 1.0$

Section 1.8.3, p. 5-29 - Unbraced Frames

During the load test, the test structure ME-295085 SH2 deflected.

For unbraced frames, it is recommended that $K \geq 1$, so choose K = 1.

As before, L = 44.0625".

r is defined as the governing radius of gyration:

(R is the actual physical radius of the rod)

$$r = \sqrt{\frac{I}{A}}$$

$$I = \frac{\pi R^4}{4}$$

$$\rightarrow r = \sqrt{\frac{\frac{\pi R^4}{4}}{\pi R^2}} = \sqrt{\frac{R^2}{4}} = \frac{R}{2} = 0.375"$$

As before, the rod material is C1045 cold drawn steel:

$$E = 30 \times 10^6 \text{ psi} = 30{,}000 \text{ ksi}$$

$$F_y = 77{,}000 \text{ psi} = 77 \text{ ksi}$$

Compare $\frac{KL}{r}$ and C_c

$$\frac{KL}{r} = \frac{(1.0)(44.0625\text{ in})}{(0.375\text{ in})} = 117.5$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2\pi^2(30{,}000\text{ ksi})}{(77\text{ ksi})}} = 87.7$$

$$\frac{KL}{r} > C_c$$

Section 1.5.1.3.2, p. 5-19

F_a is the axial compressive stress permitted (in ksi):

$$F_a = \frac{12\pi^2 E}{23\left(\frac{KL}{r}\right)^2} = \frac{12\pi^2(30{,}000\text{ ksi})}{23(117.5)^2} = 11.19\text{ ksi}$$

Maximum allowable force:

$$A = \frac{\pi d^2}{4} = \frac{\pi(1.5\text{ in})^2}{4} = 1.767\text{ in}^2$$

$$AF_a = (1.767\text{ in}^2)(11.19\text{ ksi}) = 19.773\text{ kips} = 19{,}773\text{ lbs.}$$

This corresponds to an oil pressure of

$$\frac{19{,}773\text{ lbs.}}{\frac{\pi(2\text{ in})^2}{4}} = 6{,}294\text{ psi}$$

The Euler column calculation determined the actual failing point of the rod, which was at a much higher force than we used in the load test. On the other hand, the AISC method gave a force that was close to our test force. However, the AISC calculation has an inherent safety factor built into the equations. This results in a calculation of a safe operating force, rather than the true buckling force. Therefore, our test pressure of 7000 psi oil pressure, or about 22,000 lbs. of force, is a safe and conservative number.

Procedure:

The EC drive cylinder (MC-279372) was tested in compression at 7000 psi, with the cylinder rod extended 38-1/2".

Preparation for the test:

1. Locate, in a safe place (in a corner away from normal traffic), test fixture ME-295085 SH2, cylinder MC-279372, and all parts assembled per drawing ME-295085 SH2.

2. Assemble 10,000 psi hydraulic pump with advance-neutral/hold-retract manual 4-way directional valve (pump mounted Enerpac VM-4) as the main control valve. Each line from the 4-way valve (one to rod end, one to cap end) will consist of a 10,000 psi gauge, V-8 manual shut-off valve and hose.

3. After connecting the hydraulics, run the cylinder back and forth several times, with the rod end not connected to the test fixture. This will get the air out of the oil, and allow flow regulation with the V-8 valves.

EC Drive Cylinder Load Test

5/13/91
John Wu

Test Procedure:

1. Open the rod side V-8 valve all the way.

2. Pressurize the cap side of the cylinder by directing oil flow with the 4-way valve.

3. Control the oil flow with the V-8 valve.

4. Bring the gauge pressure up slowly. Stop at anytime if hydraulic or mechanical failure is eminent or has occurred.

5. Test the cylinder pressure by running it up slowly to 5000 psi and holding for 2 minutes. Then run the pressure to 7000 psi and hold it for 2 minutes. Note that the maximum pushing force is 24,000 lbs., or 7639 psi.

6. Record all data in an engineering note.

Test Results:

The following is a list of the test results observed:

1. The pressure was raised to 5000 psi, and there was approximately a 1/8" deflection across the 36" length of rod.

2. Then the pressure was raised to 7000 psi, and the deflection increased to approximately 1/4".

3. The test structure itself deflected and bowed so that the middle raised off the ground.

4. There were no oil leaks except for a small leak at the hose connection on the cap side.

5. The cylinder did not blow any seals or oil.

6. The direction of the rod deflection was approximately angled at 45 degrees from the top of the rod.

7. The cylinder pressure was released, then it was pressurized again, and this time, the first noticeable deflection occurred at about 2100 psi. The deflection was about 1/16".

8. At 4800 psi, the deflection was approximately double in size, or 1/8".

9. At 6500 psi, the deflection reached about 3/16".

10. The cylinder was pressurized up to 7500 psi, which was still a plastic deflection, because when the pressure was released, the rod returned to its original state.

11. The actual structure will be stable and will not deflect like the test structure did.