Summary of Barrel Movement Test along HF Truck Rails

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Draft Version

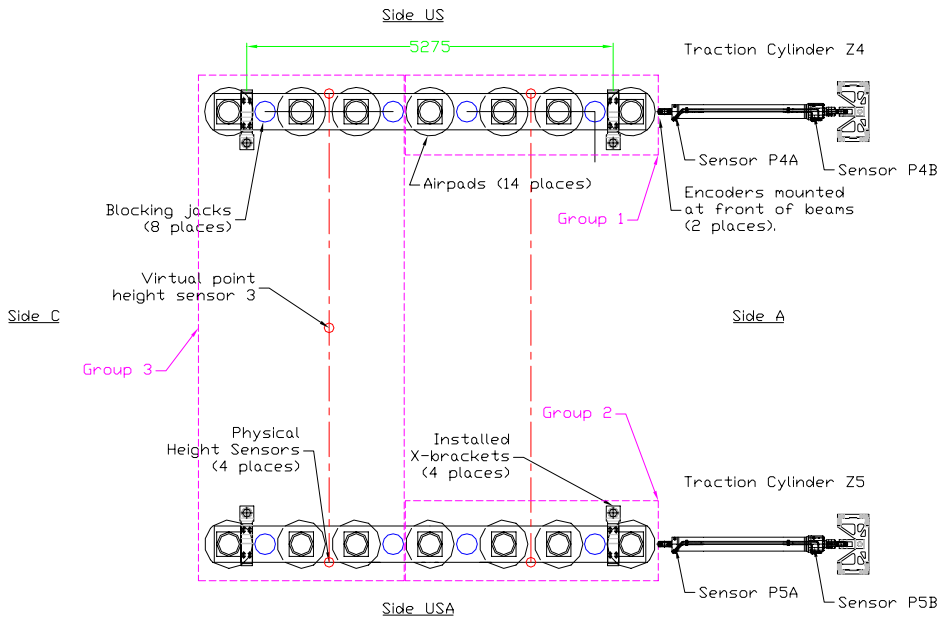

Figure 1. Layout of components and sensors for barrel movement test.

1.0 OVERVIEW

A first test movement of the barrel detector was performed using all of the final movement hardware and control system components. The primary goal was to demonstrate horizontal movement while being supported on airpads. Due to scaffolding in place for ongoing work on the barrel calorimeter, the allowable Z-direction motion (along the beamline axis) was limited. The test involved lowering the airpads to the rail and transferring load from the blocking jacks to the airpads, pressurizing the airpads with air, and then driving the traction cylinders to move the barrel in the Z-direction along the rail.

The test was successful both in demonstrating that the system is capable of moving the barrel and also revealed areas of the system that need further understanding or improvement. In particular, the following observations were made of which each is further detailed in the captions of subsequent figures. The layout of the movement hardware and location of various sensors is shown in figure 1 and the summary plot of the motion and forces is shown in figure 2.

1. Airpad cylinders slowly lost height as soon as proportional valve was closed.
2. Motion characteristic of stick slip friction was observed.

3. The stick slip motion occurred both as in phase motion where both sides of the detector advanced and stopped at the same times and also as out of phase motion.
4. The detector rotated about the Y-axis in opposite directions depending on the direction of motion.
5. The measured force to move indicated a varying friction coefficient of 1.4-1.8 percent during the motions.
6. The maximum measured force differential between the two cylinders was just over 3 tons.
7. Electrical noise corrupted the Y-sensor data values.

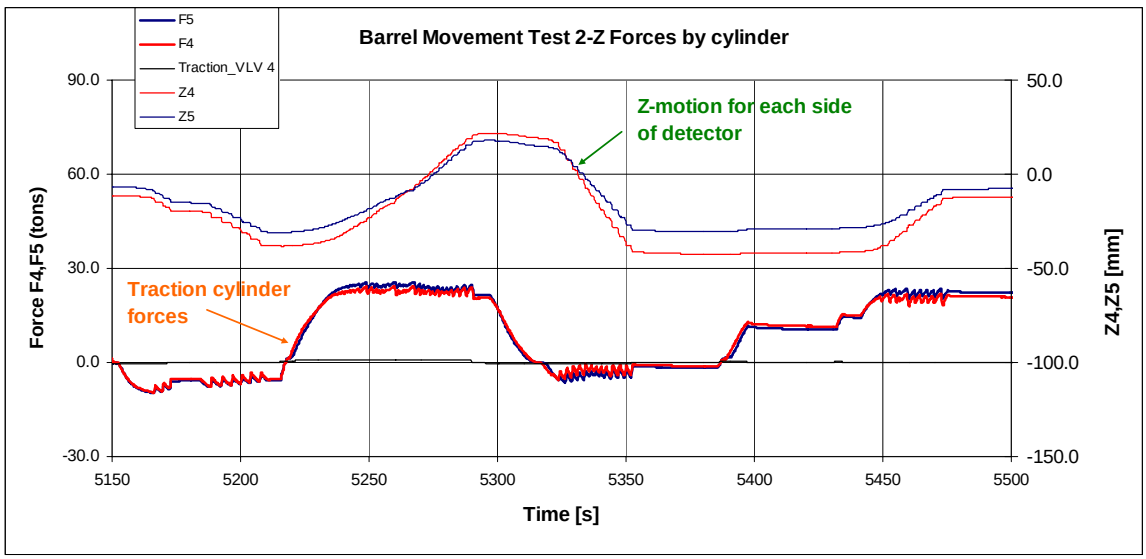

Figure 2. Data taken during movement portion of the test. Barrel raised on airpad cylinders and airpads pressurized with air. Though not observable in any data, some airpads developed proper air seals while others did not. This clearly contributed to higher than expected friction values. The detector was moved in each direction twice starting in the downhill (toward IP) direction. The second movements of each respective direction used a 4 ton less force per traction cylinder indicating improved sealing during the motion.

2.0 DISCUSSION OF RESULTS

2.1 Traction Cylinder Forces and Friction Coefficent

The forces to move the barrel in the Z-direction is made of two components; the load due to the incline of the rail and the frictional force of the airpads. When the nominal friction coefficient of 1% is assumed, these two components are nearly equal with the gravity load being larger. This implies both that the force to move downhill is relatively small and in fact directed uphill such that the cylinders are "holding back" the otherwise free falling load. In the uphill direction, both components add requiring a relatively large force to move uphill.

Appendix A details the calculation for the traction cylinders and the resulting values when using 1% friction. Friction in the Z-direction due to the X-brackets is considered negligible so long as the force difference between cylinders is not large (3 tons meets the definition of not large).

Figure 2 shows and overview of the individual forces measured for each traction cylinder during the movement portions of the test. From this, it can be seen that the forces needed for movement are higher than expected with a 1% friction coefficient. It is also seen that the forces vary during the motion which would indicate variations in the airpad friction. From the measured force values, the friction coefficient was found to vary between 1.4 and 1.8%.

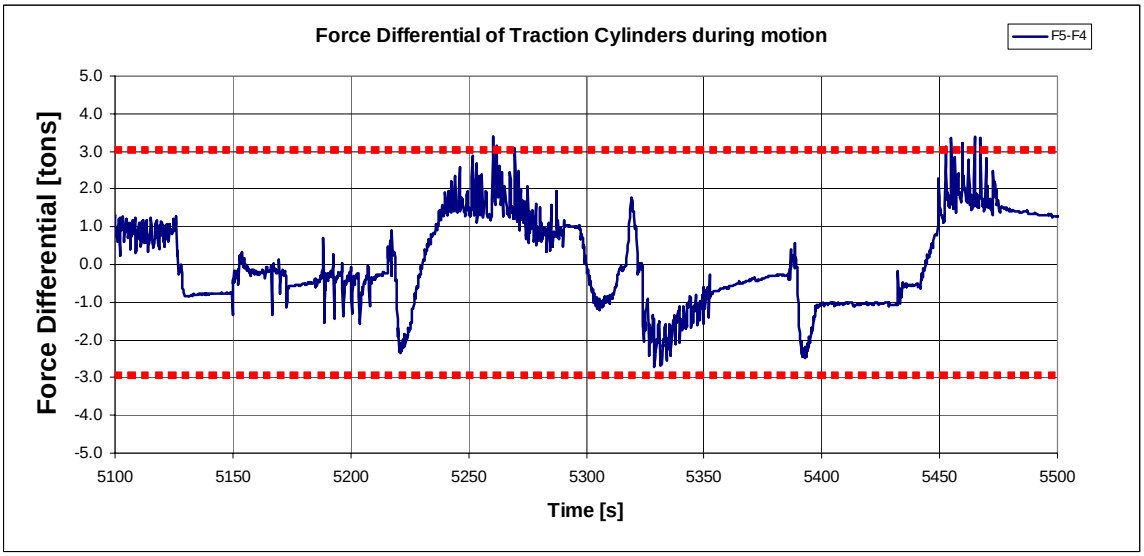

Figure 3. Plot of force difference between traction cylinders.

During movement, it is important that the force differential between the two traction cylinders is not excessive as this will force large contact forces with the X-brackets which then transfer undesirable twisting forces to the barrel [1]. As the cylinders are connected isostatically, the forces are expected to remain balanced. Figure 3 shows the force differential during the motion. The maximum force differential is approximately 3 tons. Figures 4 and 5 show views of the forces over a shorter time scale and these help illustrate the nature of this force difference. Due to the stick slip nature of the motion, the force needs to build up to overcome the static friction. Upon exceeding the threshold for motion, the cylinder then advances thereby releasing pressure and therefore the force drops relatively quickly. It is during this pressure release that we see the largest force differentials occur. All of this shows that the both the iso-static principle is effective in keeping the force differential low but that there is a finite differential possible and there is a time constant associated with the equalization of any suddenly applied (or removed) forces. See appendix B for discussion of force measurement accuracy.

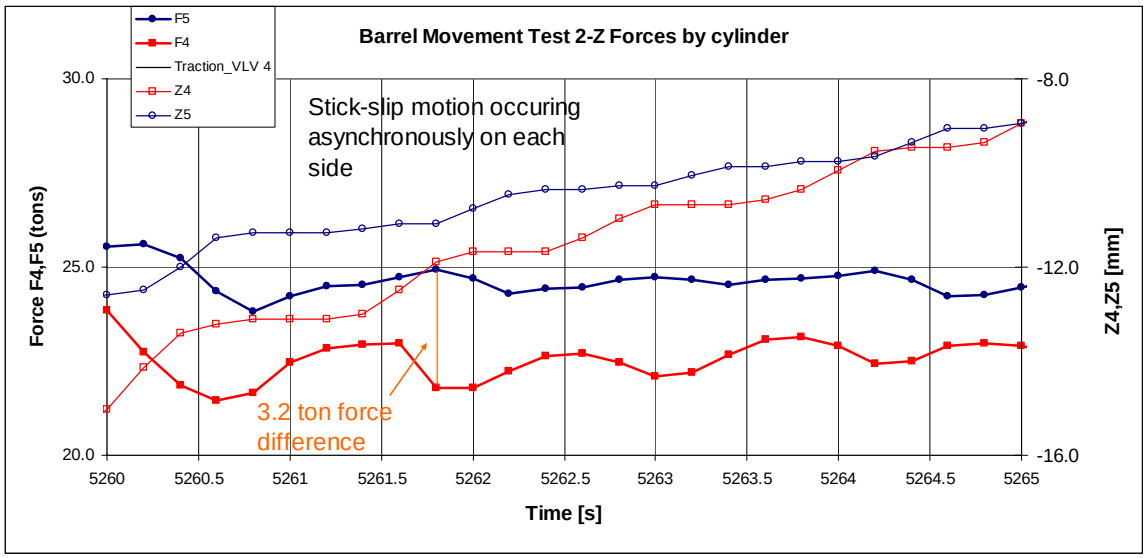

Figure 4. Closer look at variation of force during motion. Traction cylinder forces vary consistent with the stick slip motion for the respective side of the detector. The stick-slip action is seen here to be out of phase. It is seen that the maximum force differential results at the point that one of the cylinders loses pressure rapidly as a result of a slip.

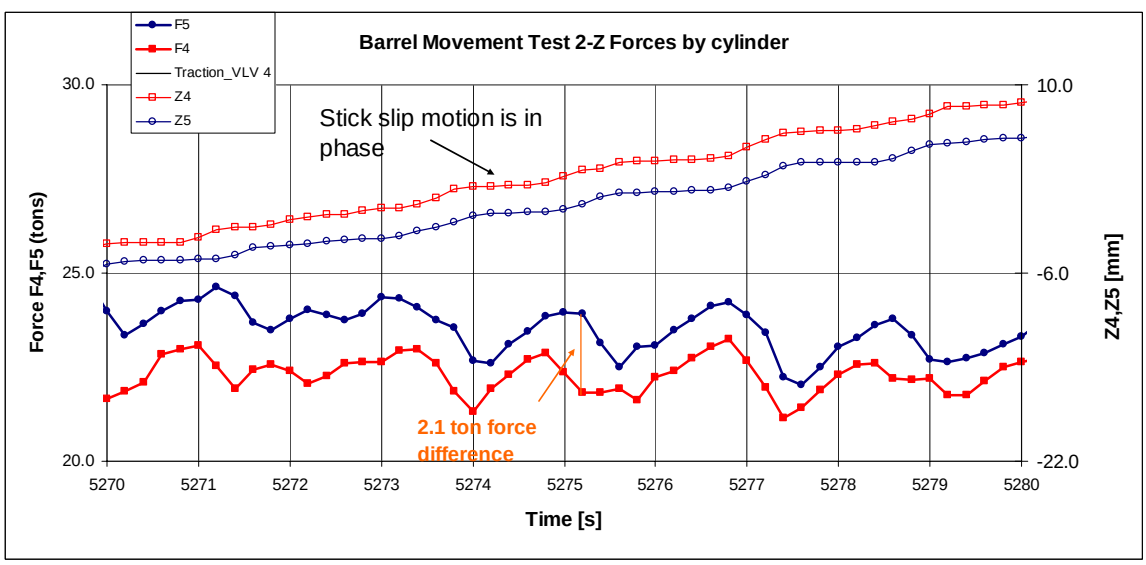

Figure 5. A short time later from Figure X, we see the stick slip motion synchronizes resulting in more closely in-phase variation of the cylinder forces resulting in lower nominal as well as maximum force differentials in the time segment shown.

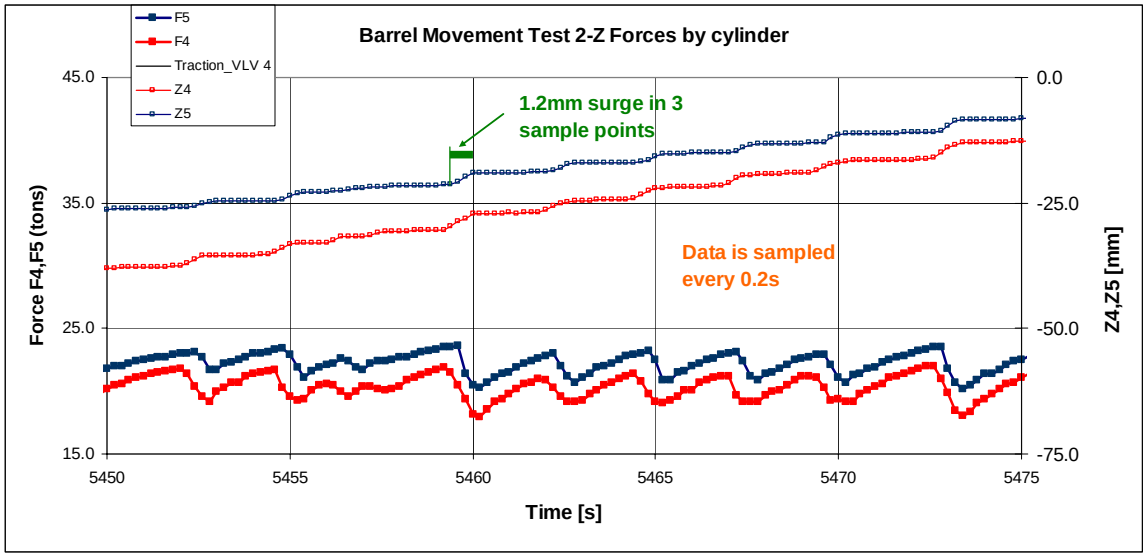

Figure 6. Close up view of second uphill movement showing stick-slip friction.

2.2 Stick-slip friction

Also evident from the plots 2, 4-5 is a surging motion that is believed to be caused by stick-slip friction. This occurs due to the difference in static and kinetic friction of the airpads during sliding. For this to occur there must also be a source of compliance in the system. There are several sources of compliance in this system including the flexibility of the hydraulic hoses, increased compressibility of the hydraulic oil (normally considered incompressible) due to entrained air in the oil, trapped regions of air due to insufficient oil purging, and flexibility in the Z-bracket. From observations during testing of the Z-brackets prior to the movement test, it is believed that there existed large amounts of air in the traction cylinders making this the greatest contributor to the problems in this test. Nonetheless, this stick slip motion was observed in previous test movements of the HF truck and during the airpad tests at ANL [2]. It was believed that these problems stemmed mostly from friction problems due to poor sealing. In tests when the friction coefficient was found to be as low as 0.8 %, the stick slip problem was not present. As indicated previously, the friction coefficient was higher than expected and was likely also a major contributor to the problem. In this test, there was insufficient time to improve the airpad seal and so this was not examined.

Figure 6 shows and example of the motion on a smaller time scale. The periodic nature of the force and motion is consistent with stick slip. In this case both sides of the detector move synchronously.

2.3 Airpad pressure and height loss

Figure 7 shows a summary of the test with respect to the airpad pump pressure and the detector height. More detailed views of the height loss problems are shown in figures 8 and 9.

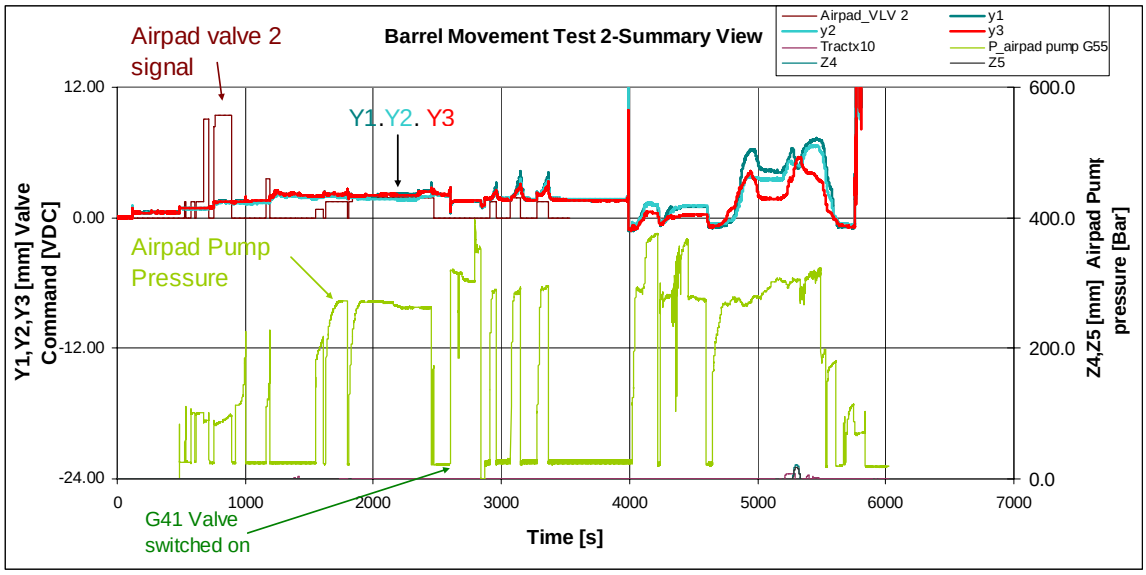

Figure 7. Overview of test showing airpad pump pressure and height variation with valve opening and closing. Pressure sensors on the airpad cylinders were inadvertantly connected to the B-side of the cylinders and therefore were not useful in measuring the load on the airpads. The pressure at the airpad pump is the best indicator of what was happening in the airpad cylinders. Valve G41 which allows and alternate flow path for some of the fluid was off for a significant time in the beginning of the test which was preventing pressure from building in the airpads. As shown in the chart, after switching this valve on, higher pressures were obtainable and increases in the height were observed at the height sensors. By examining the areas where the airpad valves were on (indicated by a signal other 0 VDC on Airpad Valve 2 signal), it can be seen that the height increased to a limiting value while the vale was opened and then lost height rather quickly upon closing of the valve.

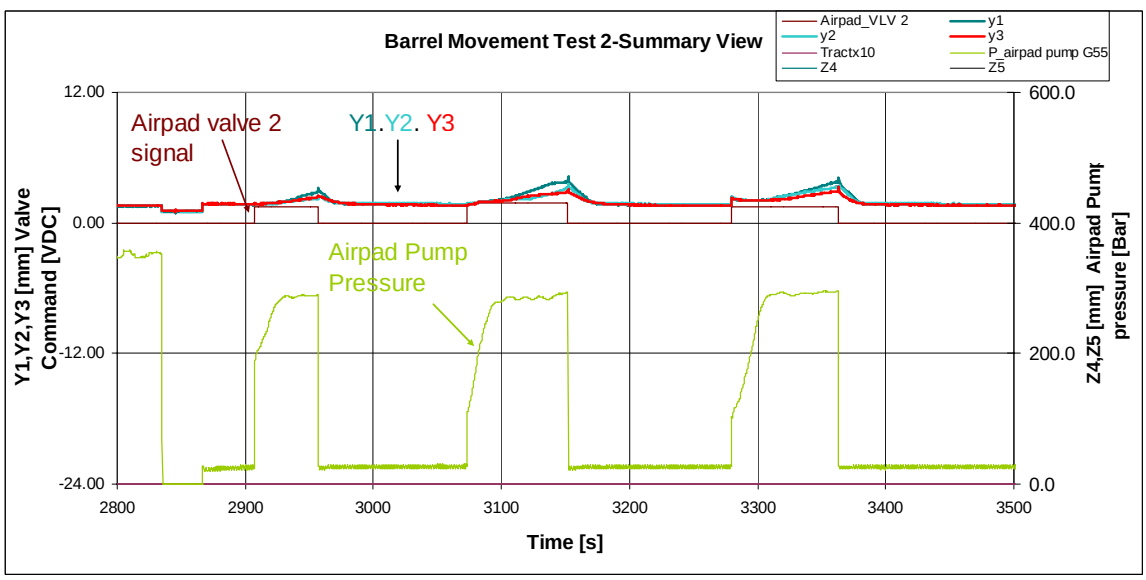

Figure 8. Repeated attempts to raise the airpad cylinders and the observed loss of height upon returning the valve to the zero position.

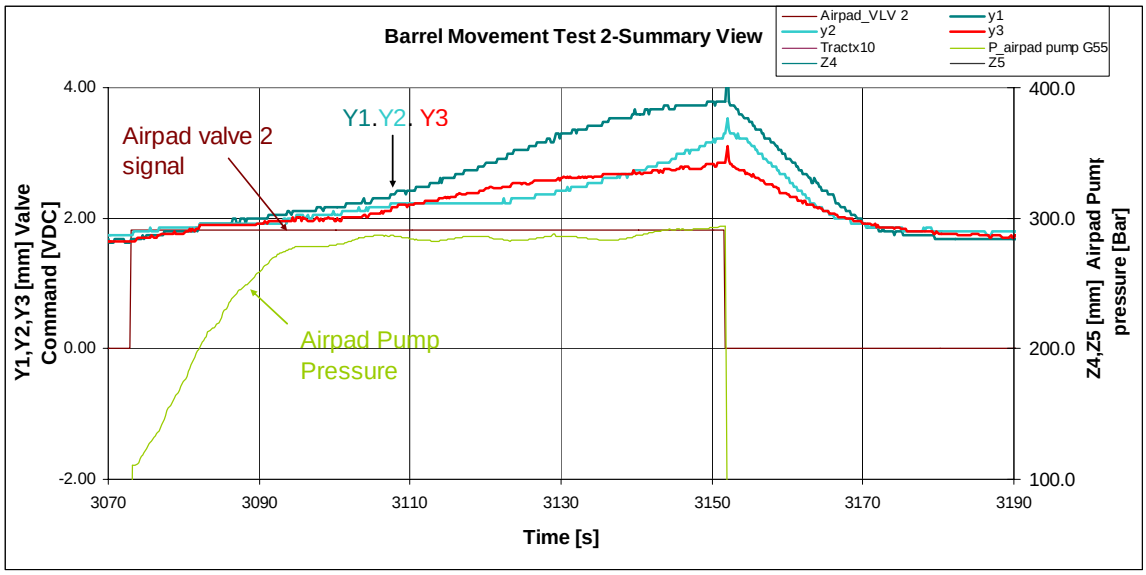

Figure 9. A close view of the raising and loss of the airpad height. The time for the airpad pressure to raise from 100 to 280 Bar is long as is the height increase indicating low flow rates for the system. The valves were open to 20% but the pressure drop across the valve was likely very small. Given the pressure drop going backwards is very large, are leakage flows in the spool valves allowing the height loss?

3.0 CONCLUSION

The movements test was successful in demonstrating the basic function of the hydraulic and control system and also in identifying areas that need attention or further understanding. Most importantly is the need to understand the problem with the airpads and the plan is to take better care in purging air from the cylinders. Similar purging of the traction cylinders and lines is needed.

An additional area of concern was the airpad sealing though as mentioned not much effort was put into this. Proper sealing of the full 14 airpads needs to be demonstrated and a method of informing the control system of any poorly sealed airpads is needed. An additional movement test after these problems are addressed could then further determine if the stick slip friction is a problem.

Proper height sensors need to be selected that are immune from noise problems and the traction sensors should be replaced with the HAWE type sensors.

4.0 REFERENCES

1. Vic's paper about 18 modules movement.
2. HF truck test summary
3. Airpads tests 12-14
4. Cylinder forces test

Appendix A. Traction forces for Barrel Movement

	Extended barrel			
Input values				
m	1600	tons	mass of Barrel	
theta	0.01236	rad	rail inclination	
μA	0.010		airpad friction coefficient	
Diameter A-side cylinder	170	mm		
Area A-side cylinder	22698	mm^2		
Diameter B-side cylinder	120	mm		
Area B-side cylinder	11310	mm^2		
Friction force	78,474	N	per cylinder	
	8.0	tons		
Gravity Force	96,999	N	per cylinder	
	9.9	tons		**PA [Bar] min**
Fcyl_up	175,473	N	per cylinder (v>0; away from IP)	77
	17.9	tons		
Fcyl_down	18,525	N	per cylinder (v<0; toward IP)	16
	1.9	tons		

Table A1. Nominal force calculation assuming negligible friction in Z-direction due to X-brackets rollers.

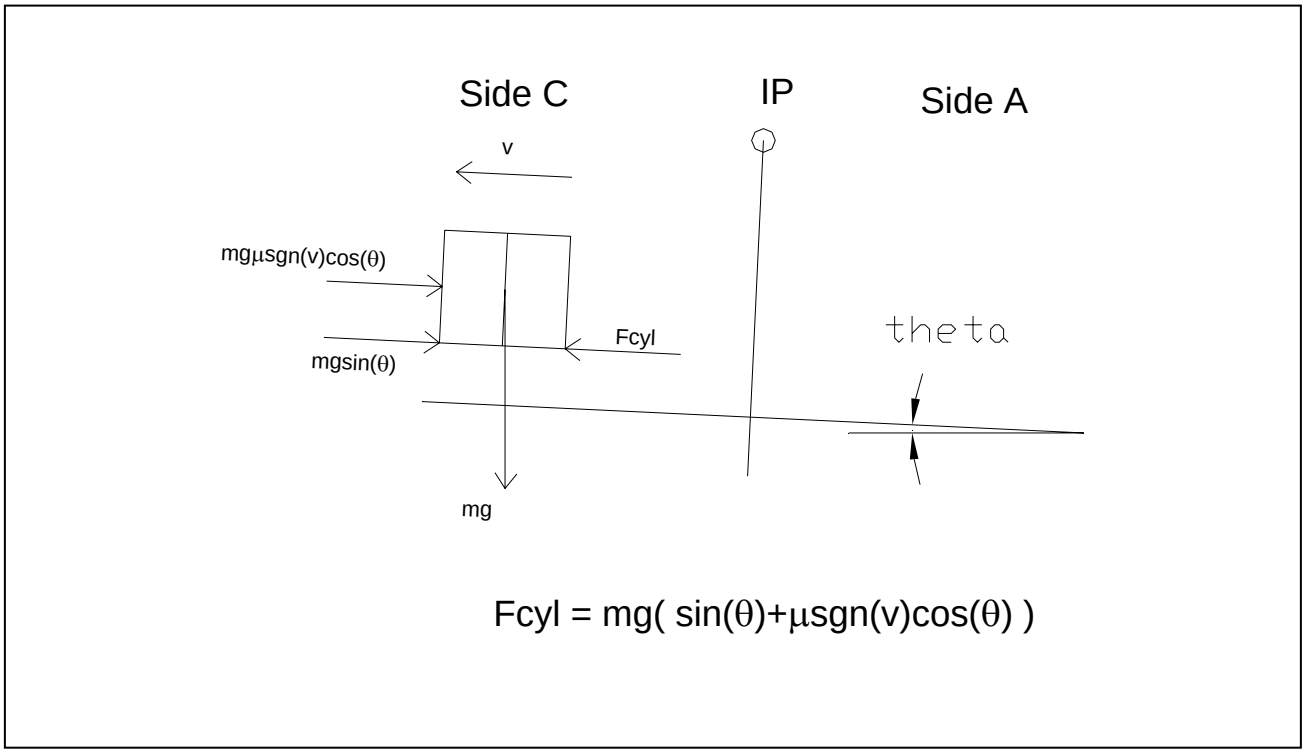

Figure A1. Free-body diagram of forces to move barrel detector in constant velocity state. It is assumed forces are uniform in X-direction (into the page) reducing to a 1-D problem.

Appendix B. Commentary on accuracy of force measurement

A final note is made about the accuracy of the sensors. The pressure sensors used for the traction cylinders (Honeywell, BL series, 4-20mA) each have unique non-zero offset currents at 0 Bar pressure readings that must be taken into account. These offsets were determined prior to the test and it is assumed that they were not effected by electrical noise of the pumps or other devices. The pressures in the cylinders at the beginning and end of the test were within 1 bar of each other. This is as expected since at these times, the cylinders were not exposed to a load and therefore the cylinders should arrive at the same pressures. This indicates that the force differential measured during motion is real. The cylinders themselves have an internal force due to seal friction that is in the range of 0.5-1 ton though it should be expected that these are similar and should not greatly effect the force differential. (Quantify accuracy are force measurements). It is recommended that these sensors be replaced with the HAWE type sensors used for the airpad pressure readings which do not appear to have the same offset problem. Flowing oil past the sensors can also alter the pressure readings though it is expected this effect is negligible in this case due to the way the sensors were mounted and the relatively low flow rates they would have seen. Additionally, the cylinders have an

The only tests done to confirm thee validity of the force measurement have shown the force sensors to over estimate the absolute force by 10% [4]. This was in a different set-up where the sensors were more affected by dynamic forces of fluid motion than is expected in this case.

Appendix C. Coupling of Z4 encoder to Y1 height Sensor

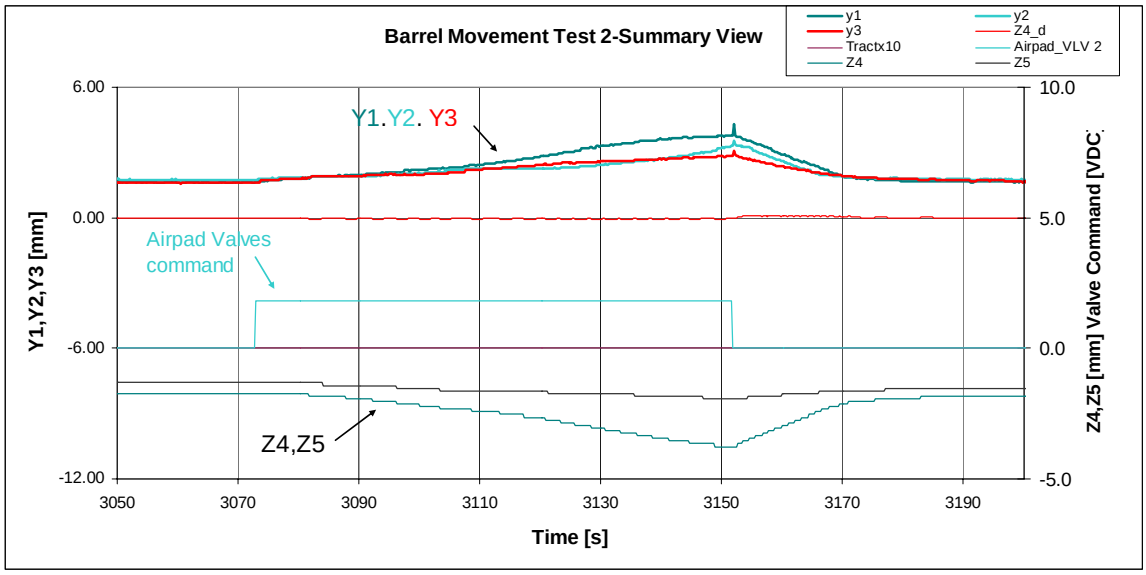

Figure C1. Data during opening and closing of airpad valve hydraulic cylinders prior to air in chambers and with traction cylinders closed. While valve is opened, height increases to a limiting value. Upon closing of valve, height decreases presumably until point where the blocking jacks are in contact. Since the Encoders (particularly Z4 side) were not mounted precisely perpendicular to the rail (Z4 bracket roughly 40 degrees), we detect that Z motion that is coupled to the height sensor motion. This corrupts the accuracy of the Z sensor data. Due to the facts that the Y-sensor drifted due to noise, at least +/- 0.5mm but possibly more, and that both height increases at both points Y1 and Y2 effect Z4, it is not straightforward to correct this value. Despite this lack of accuracy, it is not so much as to negate the conclusions drawn from the relative Z-motion. In particular, the observations indicating the stick-slip motion as well as the rotation about the Y axis can be shown to still hold. The absolute value of the twist about Z is questionable and would require careful analysis to determine but a cursory look indicates similar rotation (+/-7mm difference in Z4 and Z5 depending on direction) in each direction after correcting for height effects.