CASE STUDY

'DIGITAL TWIN' MODELING, SIMULATION, ANALYSIS & TROUBLESHOOTING

SITUATION

Numerous uncontrolled load-lowering incidents had been experienced on the auxiliary winch of the FPSO port crane.

2 other contractors and the OEM had failed to identify the root cause of the fault.

SOLUTION

Pressure Dynamics modelled the hydraulic, electrical, controls and HMI (human machine interface) of the crane in its *Multi-functional 'digital twin' modeling, simulation, analysis, and troubleshooting* technology.

A Senior crane technician was mobilised to the FPSO offshore of West Africa to investigate the operations of the crane; that operational data then used to calibrate the 'digital twin' model. Desktop troubleshooting of the root cause was conducted in the model, the existing fault was replicated in simulation, and the rectification engineered, modeled, and simulated.

PROBLEM

Without a functioning port crane, ongoing safe and commercial FPSO operations were at risk.

The client required an alternate basis to troubleshoot the root cause of the uncontrolled load-lowering incidents.

BENEFITS

Pressure Dynamics identified the root cause of the system fault, which was a design fault in the original manufacturing of the crane.

Componentry to rectify the fault was sourced and manufactured by Pressure Dynamics and mobilized to the FPSO.

Pressure Dynamics' crane technician installed the componentry and modified the crane, then tested and re-commissioned the crane for fault-free, safe operations.

PRESSURE DYNAMICS

OVERVIEW

Numerous uncontrolled load-lowering incidents had been experienced on the auxiliary winch of the FPSO port crane.

2 other contractors and the OEM had failed to identify the root cause of the fault.

APPROACH

The Pressure Dynamics Lead Crane Technician mobilised to the FPSO with a data logger, flow meter and hydraulic oil patch test kit to conduct a series of fault-finding activities.

In parallel, the Pressure Dynamics Hydraulic Systems Engineer simulated the hydraulic system in our *Multi-functional 'digital twin' modeling, simulation, analysis, and troubleshooting* technology utilising the data recorded by the Technician to assist in determining the root cause of the uncontrolled load lowering incidents.

The root cause was determined to be the installation of a counterbalance (CB) valve with an incorrect pilot control ratio as outlined in Figure 1 below:

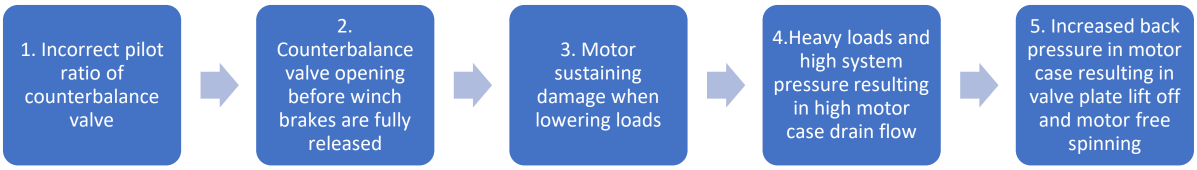

Figure 1: Root cause path

Root Cause 1 – Incorrect pilot ratio of CB valve

When Pressure Dynamics checked the CB valves on the port auxiliary crane it was set to 244 bar.

With the pressure set at 287 bar (Ppressure setting) as recommended by the OEM , a pressure of 150 bar between the motor and CB valve with SWL on the hook (Pload max), a pilot ratio of 5 ® and the factor of difference between the actual and theoretical pilot pressures taken from the starboard crane CB valve of 6 bar (Pact-diff); the minimum pilot pressure (Ppil min) required to open the CB valve with SWL on the hook is calculated below:

$$P_{pil\,min} = \frac{P_{pressure\ setting} - P_{load\ max}}{R+1} - P_{act-diff} = \frac{287-150}{5+1} - 6 = 16.8\ bar$$

Figure 2: Calculation of minimum pilot ratio

Root Cause 2 – Counterbalance valve opening before winch brakes are fully released

Counterbalance valves should be set to open after the static brake is fully released.

The auxiliary winch brake is a Dinamic Oil F906 brake pack which has a brake total release pressure of 22 bar as per Figure 3 below.

During testing it was found that the pilot pressure to open the CB valve ranged from 8 – 21 bar (see Figures 4 and 5) on the port and starboard crane auxiliary winches with loads between 53 – 88 % of SWL.

From both the actual measured and calculated pilot pressures, it is evident that the CB valve opens before the static brake is fully released.

Brake type		F 902	F 903	F 904	F 905	F 906
Static braking torque	Tb (Nm)	200	300	400	485	620
Total release pressure	pb (bar)	14	22	19	17	22
Maximum pressure	p max (bar)					300

Figure 3: Brake total release pressure

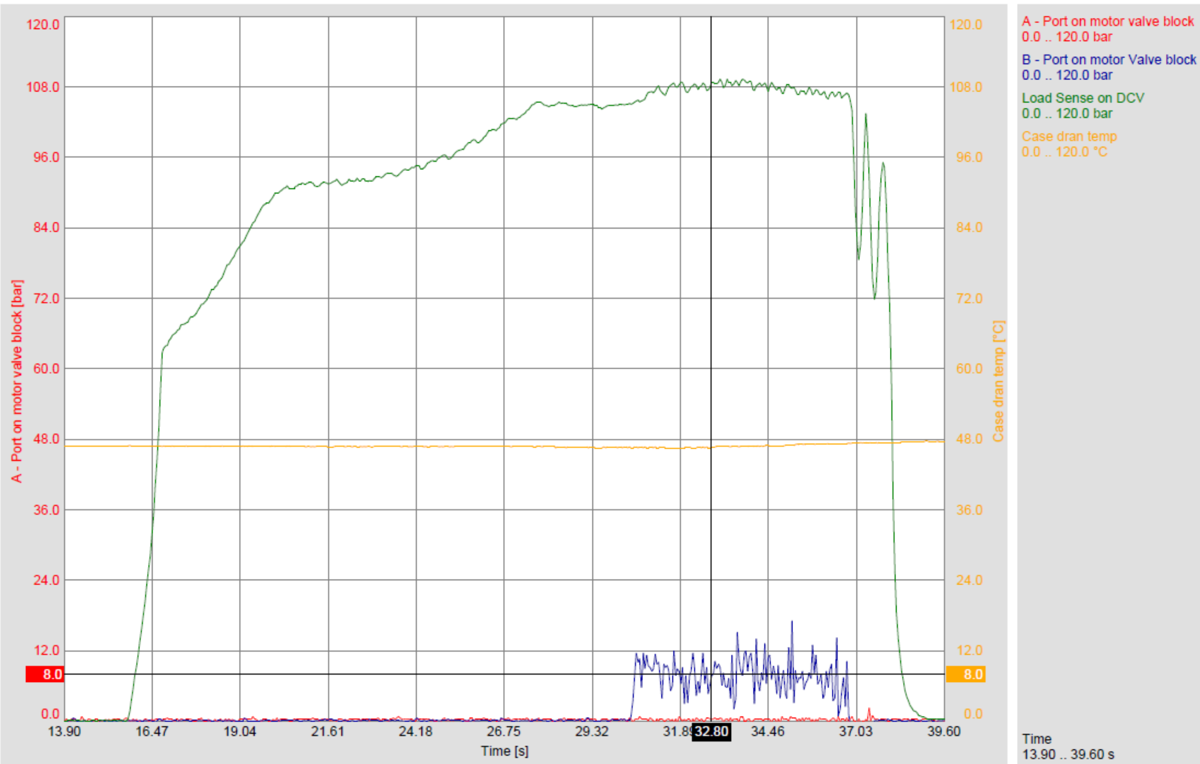

Figure 4: Port Crane - 8 bar pilot pressure to lower 6.6t load

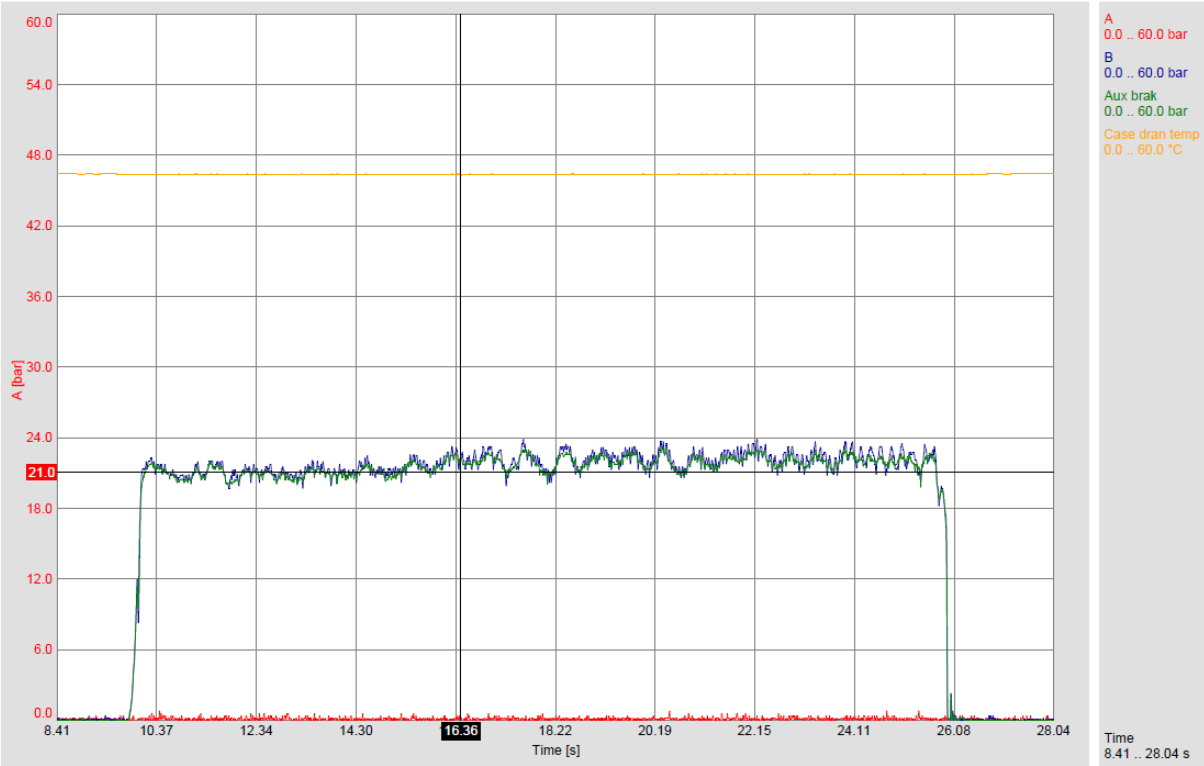

Figure 5: Starboard Crane - 21 bar pilot pressure to lower 4t load

Root Cause 3 – Motor sustaining damage when lowering loads

The CB valve opening before the static brake is fully released causes the pressure in the auxiliary winch hydraulic circuit to fluctuate resulting in the static brakes being applied and released rapidly. This causes the hydraulic motor to rotate in a stop-start manner repeatedly which damages the motor and static brake and creates heat in the system.

Specifically, it does not allow sufficient lubrication to build up on the internals of the hydraulic motor port plate and cylinder barrel face causing mechanical damage. This mechanical damage on the motor port plate and cylinder barrel face increases the more the winch is used; particularly with loads close to the SWL.

During testing it was found that the starboard crane with a 4t load (54% SWL) is currently experiencing this phenomenon. Figure 6 below shows the CB valve (blue line) opening before the static brake (green line) has opened and depicts the resultant cyclic application of the static brake due to pressure fluctuations in the auxiliary hoisting system.

The cyclic application of the static brake was also physically heard by the Pressure Dynamics Lead Crane Technician during this test.

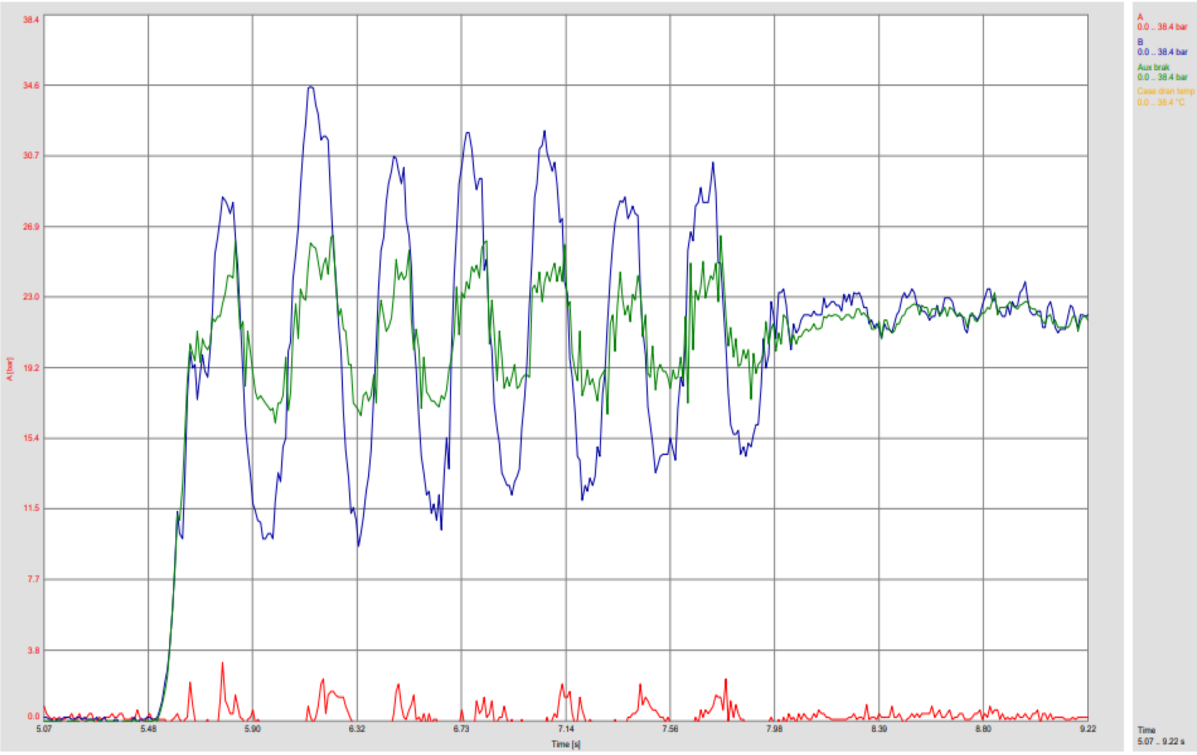

Figure 6: Evidence of the brakes not fully releasing before the CB valve can open.

Pressure Dynamics were able to inspect three auxiliary winch motors from the port and starboard cranes and found common damage between them all.

There was significant scoring evident on the port plate and cylinder barrel face and evidence of cavitation. The cavitation is a result of the scoring on the mechanical faces, creating peaks and troughs in the metal, allowing hydraulic fluid to leak out into the case of the motor.

Tables 1 – 3 show this mechanical damage on all three auxiliary winch motors that were inspected.

Table 1: Scoring on port plate and cylinder barrel – port crane auxiliary winch motor removed June 2019

Table 2: Scoring on port plate and cylinder barrel – port crane auxiliary winch motor removed April 2019

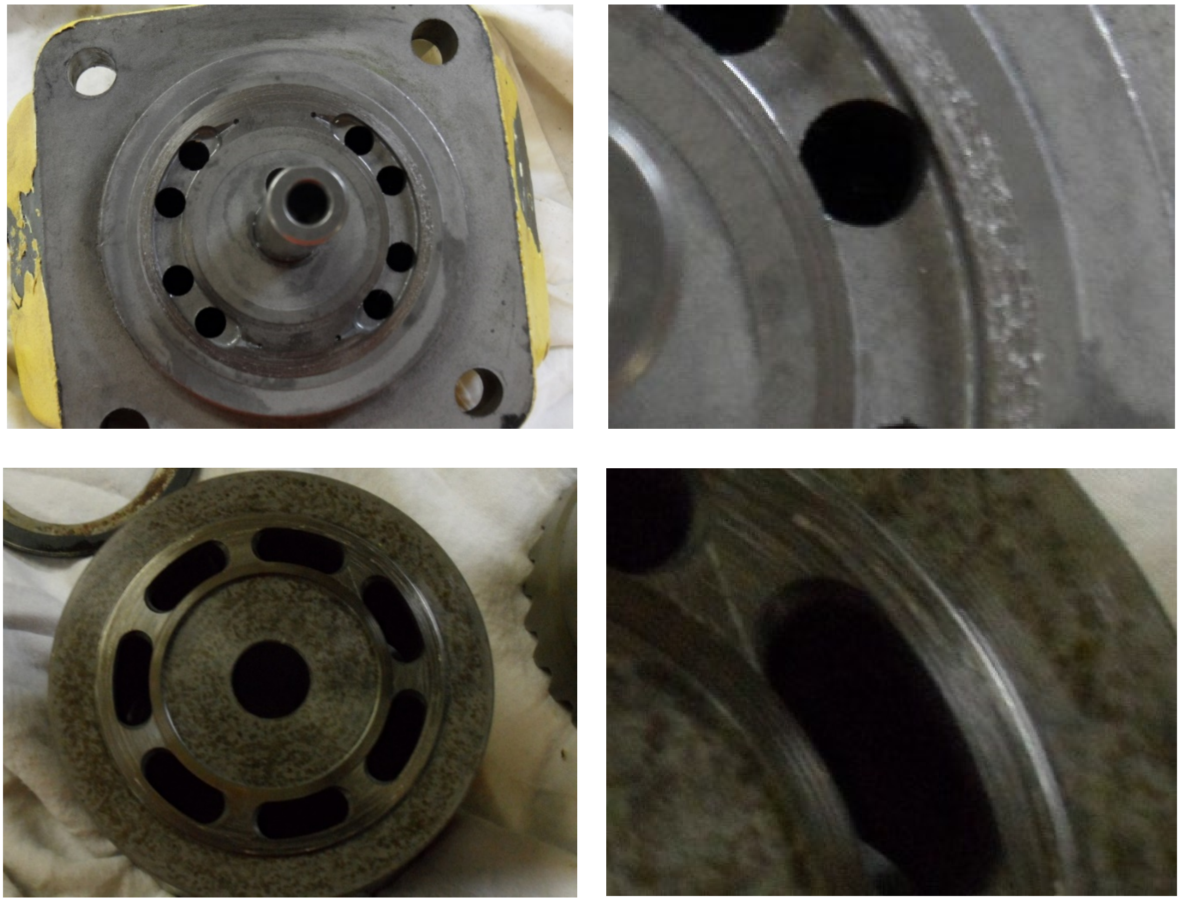

Table 3: Scoring of port plate and cylinder barrel – starboard crane main winch motor removed June 2019

Root Cause 4 - Heavy loads and high system pressure resulting in high motor case drain flow

Due to the crane functions not being individually pressure compensated, when one function is operating at high pressure it makes this high pressure available to all the other functions running on the same pump. Similarly, a higher flow rate is also provided to the other functions than would usually be provided.

During the latest incident, the crane operator had a 6.8t load on the auxiliary hook and was luffing up the boom and hoisting down on the auxiliary winch to land the load on the deck.

As both functions are powered by the same pump, a higher volume of flow than usual is provided to the auxiliary motor which, due to the mechanical damage experienced by the motor, is now able to leak through the case drain.

This high case drain flow is depicted in Figure 7 where the uncontrolled load lowering incident was simulated with a load of 6.6t (88% SWL).

The luffing function required 110 bar to luff up the load whereas the auxiliary winch motor only required 8 bar to lower the load. The pump supplies the higher pressure and flow rate and makes it available to the auxiliary motor. When the auxiliary winch was slowly operated in the down direction whilst luffing up, the case drain flow (dark blue line) spiked to between 15 – 30 L/min.

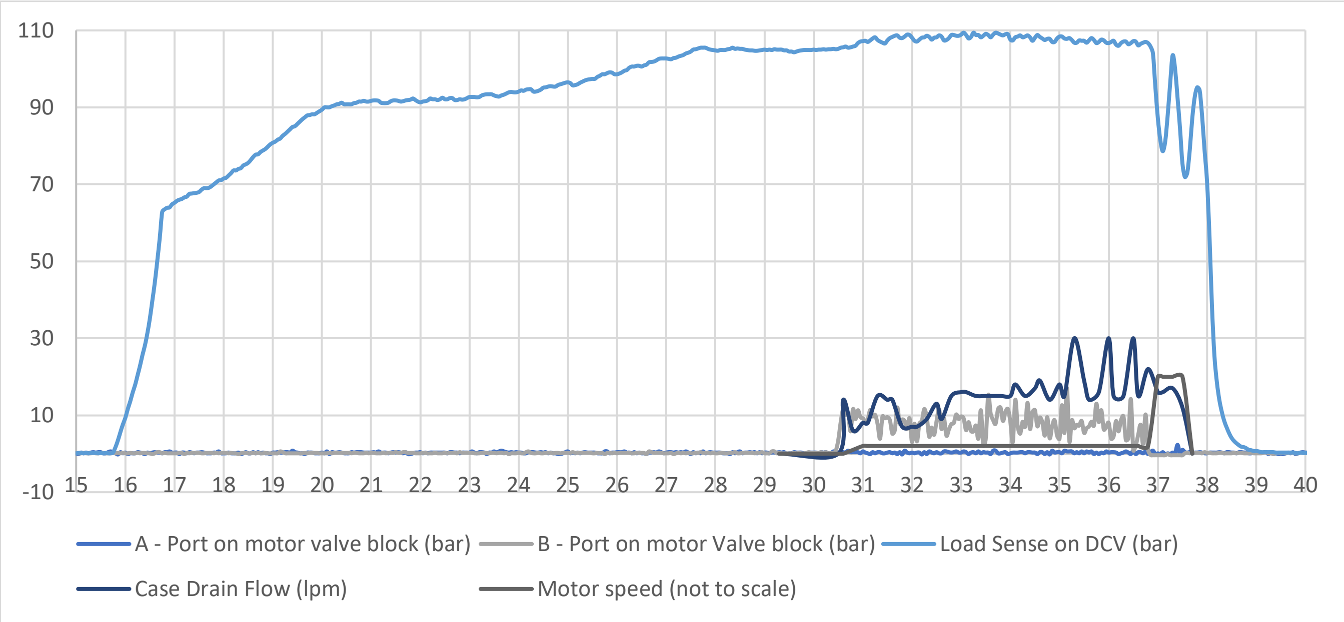

Figure 7: Port crane auxiliary motor during simulation with 88% SWL

Root Cause 5 – Increased back pressure in motor case resulting in valve plate lift off and motor free spinning

The high case drain leakage causes back pressure in the motor case to increase and disrupt the forces which normally balance the motor.

If this back pressure is high enough then it can lift the cylinder barrel off from the port plate and allow the motor to free spin which results in the uncontrolled load lowering incidents.

Figure 8 shows how the pressure is normally balanced in the cylinder barrel. The forces shown are:

- F_1 – spring force holding the cylinder barrel against the port plate
- F_2 – system pressure acting on the cylinder barrel to separate it from the port plate
- F_3 – case pressure acting on the cylinder barrel to separate it from the port plate

During normal operation in a healthy motor, the spring pressure (F1) is greater than the pressures acting on the cylinder barrel (F2 & F3); thus, the cylinder barrel and port plate are constantly in contact.

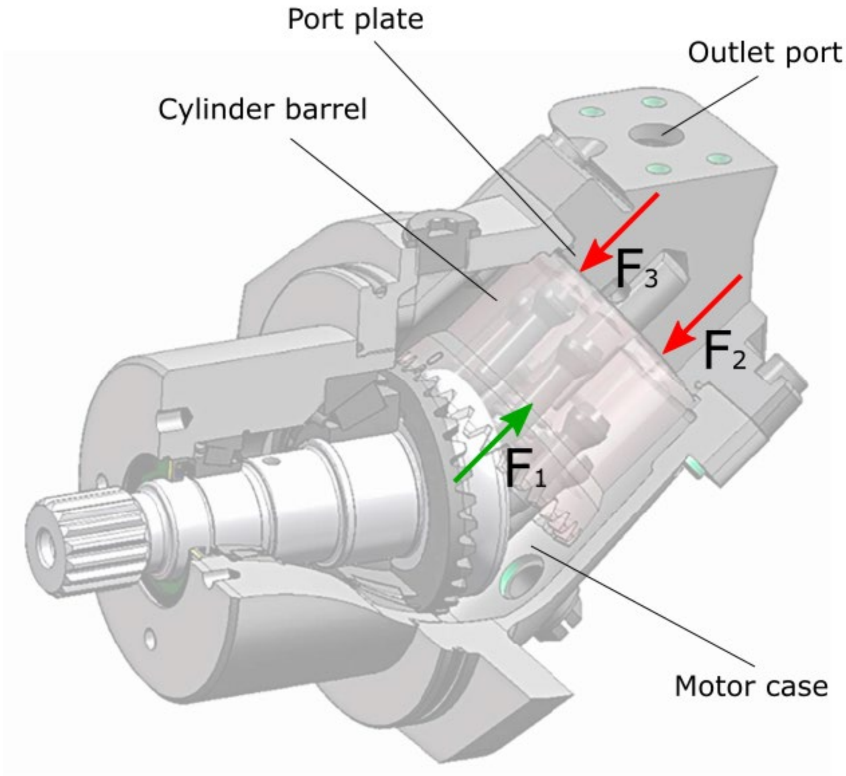

Figure 8: Motor cylinder barrel forces during operation

During testing of the port auxiliary winch with 88% SWL, while luffing up and slowly lowering the load, the case drain leakage averaged 15 L/min for 5 seconds and then spiked to 30L/min in the 2 seconds prior to the simulated uncontrolled load lowering event.

These spikes of case drain flow rates would have created the necessary case drain pressure to overcome the spring forces and separate the cylinder barrel from the port plate.

This is evident in Figure 7 where the motor speed increases significantly at the 37 second mark indicating that the motor is free-spinning, and the load is lowering uncontrollably.

RESULTS/BENEFITS

During the fault-finding investigation, the following additional faults were identified and required rectification to return the crane to full functionality.

1. Hydraulic Oil Cooler Inefficiency

It was discovered that the hydraulic oil cooling system on the port crane is not working as efficiently as it should be.

The full flow from cooling circulation pump is passing through the fan motor resulting in a pressure build-up at the motor inlet. Once this pressure reaches 750 psi (52 bar), the RV-1 relief valve is activated and approximately 12 – 18 L/min of hydraulic oil passes over this relief valve. This induces heat in the hydraulic oil and results in some oil bypassing the oil cooler altogether.

A modification was required to the cooling system to allow some of the oil to bypass the fan motor and reach the oil cooler which would reduce the pressure in the system and prevent the oil from passing over the relief valve constantly.

2. Incorrect PLC temperature control settings for the oil cooler

The oil cooler fan was set to activate at 35°C and switch off when the oil reaches 33°C. The high temperature warning alarm was set to 55°C and the high-high temperature alarm resulting in engine shut down was set to 60°C.

The optimum viscosity range for Shell Tellus T46 hydraulic oil is between 40 mm2/S at 43°C and 20 mm2/S at 63°C and the maximum recommended operating temperature for the auxiliary winch motor is 60°C so the temperature control settings should be adjusted to maintain the oil temperature between 43°C and 60°C.

The Lead Crane Technician changed the settings so that the oil cooler fan starts at 53°C and shuts off at 45°C. The high temperature warning alarm and high-high temperature alarm were also set to 60°C and 70°C respectively which is as per the original OEM specifications.

These settings allow the crane operator sufficient time to complete the lifting operation and allow the hydraulic system to cool down rather than shutting down the crane engine mid-lift.

3. Deadman switch controlling the cooling circuit

A modification to the cooling circuit had been completed however, during the investigation it was discovered that the modification had not been installed correctly.

4. Check valve missing on the winch motor case drain

During the fault-finding investigation it was discovered that the winch motor OEM recommends that the housing pressure must be equal to or greater than the external pressure on the shaft seal.

To achieve this, they propose that a 0.5 bar spring-loaded check valve is fitted to case drain line of the motor. This check valve was found to be missing on all motors, so Pressure Dynamics procured 4 x 0.5 bar Fluid-Press FPR ¾" check valves and the Lead Crane Technician fitted them to the port crane main winch motor and starboard crane main and auxiliary motors.

5. Poor quality of hydraulic oil

Numerous hydraulic oil samples were analysed and found to have a cleanliness between NAS 9 to NAS 11 which is far above the recommended NAS 7 (ISO 18/16/13) for the system.

Furthermore, the oil samples were found to have an average water saturation level between 45% to 65%.

6. Potential contamination in the hydraulic system

Due to the wear of the hydraulic motors and water saturation of the oil, there is a strong possibility that there are metal and water contaminants remaining in the hydraulic system.

Given the contamination and age of the hoses, it is recommended that all the crane's hoses are replaced.

The spools in the Control Valve Manifold should also be removed and inspected for signs of wear damage from contaminants.

Given the auxiliary winch has experienced multiple uncontrolled load lowering incidents and the introduction of metal contaminants to the system via the mechanical damage to the auxiliary motor, it is recommended that the auxiliary winch directional control valve (DCV) is replaced.

7. Crane functions not set to the correct speed

During the fault-finding investigation, it was discovered that the speed on the auxiliary winch was set to 98 m/min whereas the OEM specifies a speed of 60 m/min.

The Pressure Dynamics Lead Crane Technician checked and adjusted all speeds on the crane function amplifier cards to be within OEM specifications.

8. Damage to the brake and sprag clutch

The brake and sprag clutch were stripped down and inspected by the Pressure Dynamics Lead Crane Technician to identify whether any damage had been sustained due to the uncontrolled load lowering incidents and the cyclic application of the brakes during load lowering operations.

Following componentry inspection, it was found that there was significant scoring on the motor to gearbox shaft where the sprag clutch is fitted and the shaft bearings also exhibited signs of heat damage.

Similarly, the disc carrier gear had deep scoring where the sprag clutch cams contact and the cams themselves were also damaged and it was recommended to replace the entire brake pack.

Table 4: Brake pack damage

9. Load sense line orifice is missing

During the fault-finding investigation it was discovered that the OR2 orifice in the load sense line for the system pump was missing which resulted in pressure spikes during crane operation.

10. Hydraulic hoses with incorrect pressure rating

The main pressure relief valve at the Control Valve Manifold (RV1) is set to 276 bar; however, the hoses in the luffing and jib systems are rated to 3,000 psi (207 bar).

CONCLUSION

Pressure Dynamics' application of *Multi-functional 'digital twin' modeling, simulation, analysis, and troubleshooting* technology and subject matter expertise resulted in identification of the root cause system fault, which was a design fault in the original manufacturing of the crane.

Componentry to rectify the fault was sourced and manufactured by Pressure Dynamics and mobilized to the FPSO.

Pressure Dynamics' Lead Crane Technician installed the componentry and modified the crane, then tested and re-commissioned the crane for fault-free, safe operations.