



**DYNAMIC POSITIONING CONFERENCE**  
**15<sup>th</sup>-16<sup>th</sup> November, 2005**

**Risk Management Session**

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**Mixing Dynamic Positioning**  
**And Moorings**

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**Summary**

In the past the term dynamic positioning has been used when thrusters are automatically controlled to reduce mooring line loads or to help keep a tighter watch circle. In the new ISO document on station keeping a clear separation has been made between dynamic positioning and thrusters assisted moorings.

This paper outlines the key elements of this new standard and then provides some feedback on an FMEA and full-scale trials of a thruster assisted system installed on a DP class 3 drilling semi submersible. During this process several potential pitfalls based on older systems used for flotels were investigated and the ways of getting round them fully tested during a week when the rig was fully moored at a dummy location specifically for this purpose.

The results and a dramatic drive off have caused some rethinking by the system designers. The history station that was also installed and working enabled all the parameters to be checked and the incident to be graphically displayed and easily understood. It also enabled a close out by simulating all the contributory factors and showing how a drive off from these circumstances can be avoided in future. This paper will illustrate the causes of the incident and the great benefit of the history station in understanding the control system for thruster assisted moorings.

### References

1. ISO TC 67/SC 7/WG5  
Part 7: Stationkeeping requirements for offshore structures and mobile offshore units
2. Thruster Assisted Moorings C A Jenman  
The Future Development of the North Sea and Atlantic Frontier Regions Aberdeen 25-26 January 1995
3. IMO MSC Circular 645 Guidelines for vessels with dynamic positioning systems
4. IMCA M103 Guidelines for the Design and Operation of DP Vessels

### ISO Standard for DP and Thruster Assisted Moorings

In the ISO document (Ref. 1) thrusters-assisted moorings is defined as a stationkeeping system consisting of mooring lines and thrusters. The thrusters contribute to control the structure's heading and to reduce mooring line forces and reduce structure offset.

To determine the amount of thrust that can be allowed in mooring calculations not only must the thruster's efficiency be taken into account but also the worst case failure and long term thruster availability. The latter being important when thrusters cannot be removed or repaired during winter months on a turret moored FPSO for example. For manual control of thrusters the allowable thrust is further reduced to 70% on the basis that a manual system will use thrust in a fixed direction and that this will not necessarily be the most effective direction that should be available to an automatic system.

The standard expects the mean load reduction method to be used for spread moorings and for turret moored structures but makes the point, in the case of the latter, for adequate reservation of thrust for heading control to be made. For a ship shaped unit maintaining a heading into the environment is the best way to reduce mooring line loads. No expectation of mooring load reduction after a single line failure has been made. In earlier work in this area (Ref. 2) it was found that to be sure of reducing ..... mooring line tensions by the use of thrusters after a line break:

- there had to be additional thrust available
- the system had to wait to be sure (line break + movement in opposite direction outside intact envelope)
- the thrust had to be applied (which with CPPs takes several seconds)

In practice thrust did not reduce the peak excursion and in addition it could add to the oscillations that followed and even increase them.

The ISO document also covers dynamic positioning but does not seek to make any new requirements beyond existing rules Ref 3 and guidelines of Ref 4. It does however make a few points about failure modes for the FMEA to consider:

- the sudden loss of major items of equipment
- the sudden or sequential loss of several items of equipment with a common link

- control and monitoring instabilities and failures, and methods of detection and isolation
- faults that can be hidden until another fault occurs.

It also places some emphasis on the risk analysis that is mentioned in Ref 3 and on annual trials. There is no scope for annual trials to be carried out on a continuous survey basis.

### **The Status of Old Thruster Assist Systems**

The concept of mixing DP with moorings came about because of several factors:

- the difficulty with getting some moorings to meet the mooring codes (particularly in Norway)
- the ability to adapt a DP control system to damp motions (surge & sway) so flotels could keep a telescopic gangway connected.
- the effective marketing of this product to regulatory bodies
- the proposed new class rules that made a thrusters assist system attractive.

These circumstances were ideal for both Simrad and Cegelec to develop and sell their APM and the TAMS systems respectively.

Research in 1994 (Ref 2) showed that simple single point failures could be a major problem (increase mooring line tensions), most operators found it too difficult to use (more complicated than DP) and it could not in practice give the assistance assumed in the new rules (drilling wanted the power).

The feedback from operators at this time (only a few actually tried to use it in automatic mode) was summarised as follows:

- line break detection and compensation only active if there are no alarms from any impacts i.e. all sensors active and in limits including all anchor line tension gauges.
- there are too many faults in the system to use it
- damping mode in moderate weather better than an operator could do manually
- vessel estimator useless after a long period of bad weather so have to go back to manual
- monitoring (cable supervision mode) good
- no way back once it becomes unstable
- most unreliable feature is moving within a mooring pattern because system becomes unstable.

So it was with great interest that testing of a new system from Kongsberg Maritime was approached. Several SDPM (Simrad Dynamic Positioning and Mooring) systems have been supplied in the last 2-3 years but they have not been given an FMEA or an FMEA proving trial. The main reason for this is that these systems are used to keep the position and heading while running moorings rather than assist moorings once the spread is set. It is a great advantage to have a stable heading and position especially when the anchor handlers are not running in opposing pairs at similar tensions.

### **The New PM (Position Mooring) Control System**

The biggest difference between the old system and the new is that the DP approach of using real time data has been changed. No longer are anchor tensions taken and believed. They are not heavily filtered and believed. They are taken, together with the anchor position and line length to describe the present position and adjusted to make the maths for the selected line components, water depth etc., make sense. From that point onwards no tension 'noise' is used. A tension change will only come from a move in position as measured by the position references or the line

length. This removes one of the main problems of the old system; that of system instability from wrong or noisy data.

The Position Mooring system is a control module within the integrated DP and PM control systems, it is thus interfaced to all the various reference systems and sensors that are available to DP as listed below,

- DGPSs
- HPRSs
- Gyrocompasses
- Vertical Reference Sensors
- Draught sensors
- Wind Speed and direction Sensors
- Winch data
- Anchor line tension and length

In the PM mode the system has the following:

- Automatic monitoring of the vessel's overall mooring pattern, (length and tension of each individual anchor line).
- Automatic monitoring of the vessel position excursions and calculation of velocity..
- Possible detection of an anchor line break and the consequences in terms of excursion.

The mooring software within the system can also be used to calculate the adjustments to mooring line lengths needed to adjust the rig's position without increasing the amount of thrust that is being used. The system has facilities for wind and current input if such data is available or can be estimated accurately, these values are used in the anchor handling and PM modes.

The most important part for good PM operation is the mooring model which calculates a net mooring spread force from the individual mooring line data. This model is generated by using the anchor co-ordinates and mooring line characteristics from operator input and the measured tensions and line lengths. Errors are always present and the system has to calculate the resultant error and set it as a constant. The error is not constant but will change if an anchor drags a little or a mooring line straightens out in rough weather or a sensor drifts a little with temperature or any other parameter.

There is also a model for the thrusters that uses an rpm thrust curve to calculate the thruster force based on the speed feedback signals from the thrusters' drives. This model is also imperfect but errors here are of much less significance than the mooring model.

The model is also effected by the vessel's draught as this input is used to distribute the structure between the wind and current models. An incorrect draught input by the operators will degrade the model and the performance of the PM system. It is not possible to have a completely wrong draught accepted. This limits the magnitude of this error that can be made by the operator.

Using the basic rig model and all the above data and the system stiffness the PM system calculates the thrust needed to change the position and speed of movement in each of the three horizontal degrees of freedom - surge, sway and yaw based on the position reference data alone.

The model is inaccurate but if good positioning data is available at one second intervals it is possible to compensate for the errors particularly if the conditions are steady and the position not changing very much (< 2m). The Kalman Filtering also continuously assists the model estimates of position and heading by using the measured and accepted position information from the position-references and gyrocompasses. However if the position references degrade so will the model.

If the reference system measurements are completely lost (position or heading dropout), the model will continue to generate position estimates but in damping mode the thrusters can do nothing and in positioning mode there will be a position drop out and the mooring model will degrade. This system does not use the moorings to calculate movement or position because it is difficult to achieve accurate and stable measurements from a line tension sensor. The reference origin is also lost if there are no acceptable position references so that as soon as a position reference is back on line there is a new and different reference origin. If the difference is small (1m) the effect might be insignificant but small distances can make a large difference in the tension calculations and the whole mooring should be reset. The thrusters can be controlled manually during this time. This illustrates that the PM system is an assistance to the moorings but there will be times when it will not be completely available in a stable condition.

This PM system uses catenary equations with the following mooring line data to characterise each mooring line.

- water depth
- anchor co-ordinates
- vessel position
- line length
- initial line tension
- line parameters (such as weight in water, elasticity, bottom friction)

When deploying anchors the operator can select the measured tension or a manually entered value. Once the mooring line (with various different segments as entered by the operator if appropriate), has been set up the tension only changes with the measured position if no change in line length is sensed. So if the position references are accurate and the tension will be correct. However if the position reference is poor or erratic then so will be the tension. In fact if there is only DGPS available and there is a 10m drift off of the fix there could be high tension alarms on the mooring lines in the opposite direction of the error. So there could be a tension alarm on the leeward mooring lines!

The position mooring mode should not be selected until the vessel is fully moored under the anchor handling mode. This mode is for taking into account mooring line forces. Manual or fully automatic position and heading control can be selected. In addition just damping can be used to stop vessel oscillations. In this way this mode is different to DP. Damping should be used before entering the mooring data so the moorings are steady and as accurate as possible.

For the tension and line length inputs there is a choice of enabling the sensor or a manual input, there is also a facility for setting tension and length alarms for the lines on which the sensor is enabled. There is of course no alarm or line break detection for a line with a manual input. An incorrect manual input can destabilise the system.

Similarly there are choices for the mooring lines under “mooring system”. The operator must select NO (no mooring line in that position), MEASURED (the actual measured tension) which should be selected during the running of the anchor and CALCULATED which must be used once the anchor is set to the required tension. For the line length a similar set of choices are available but when the line is tensioned and the rig in position the measured length should be used. The measurement of length is much less noisy than the tension because it is derived from proximity switches. So with the winches not running there should be no changes in length measured and the only noise in the signal will come from the signal amplifier and the serial link taking the data to the SDPM.

When in anchor handling mode or position mooring, the system checks the line lengths and reference origin every 10 seconds to determine whether the model needs updating. When this is done a message is given to the operator. This procedure helps to keep stable positioning but it also provides a “creep mechanism” whereby there could be a slow shift in position over time.

Within a few minutes of selecting the position mooring mode the Line Break Detection function becomes active but it requires position-reference information at least once per second. This is normal for DGPS but not for HPR even if the interrogation rate is set at once per second because often a fix or two can be lost. If this condition is not satisfied, it is not possible for the system to detect line breaks. The Line Break Detection function monitors the anchor lines tensions and the movement of the vessel in order to detect single line breaks. A line break can be detected when the tension in an anchor line drops significantly and there is a corresponding change in position and heading.

In addition to a one second position update there must be accurate measurements of pitch and roll because these sensors are being used to correct offsets of the position references. If more than one mooring line fails the system will treat it as a single line break. If the wanted position and heading are not set correctly (an old position is still displayed and the rig is not in automatic position and/or heading control) then the line break detection will try to restore the rig to this position using all the thruster force available. An alarm is given and the broken line is coloured red on the Position Plot view and any tension from this line is ignored by the system.

The amount by which the system can reduce the first position excursion after the break depends how long it takes for the position and/or heading change to confirm the break. Tension reduction should not be relied upon, what is important is that there is not resonance so that the following excursions are greater. The automatic position control may not bring the rig to a stable position because the line that has been broken had a contribution to the overall constant error that had been assumed at initial set up. So after a line break alarm has been issued, the Line Break Detection function is disabled to allow the system to stabilise. If it stabilises the line break detection is automatically reactivated, if not manual thruster control can be selected and a new set point selected. To modify the mooring after a line break the operator has to select the anchor handling mode.

In the Anchor Handling and Position Mooring modes, a “Tension Optimisation” function is available it is a tension adjustment facility. However tension optimisation is the expression used to enable a mooring pattern to pass the code checks for a particular location by for example slackening off leeward lines in a storm. Tension optimisation is also the name given to adjusting the moorings in advance of a forecast storm.

This facility should be called tension adjustment for positioning as this is what it is for rather than bad weather preparation. The operator can select a mean tension for this adjustment and mean tension in this regard is the sum of the present tensions divided by the number of lines. There is a

risk here of increasing the mean tension such that the mooring pattern no longer meets the mooring code used for the mooring approval.

The system calculates the changes in line length that would be required to move the vessel within the mooring system. The operator can specify the required position of the vessel and any thruster force that he wants to have included in the calculation. The calculations take into account the current line tensions, lengths and environmental conditions. The advice, provided in terms of line length changes, is presented in a dedicated dialog box for the operator to act upon with the winches.

The PM has an online Consequence Analysis function that runs every five minutes while the system is in either Anchor Handling or Position Mooring mode. This function performs an analysis of the vessel's ability to maintain its position after a single line break or a failure in the selected thruster/ power system. Using the existing mooring pattern, environmental forces and available thruster force, the system simulates the consequences of each of the selected failures out of the following list.

- a break in a single anchor line
- a single thruster failure
- failure of a thruster group
- failure of an individual power sub-bus
- failure of an individual main power bus
- a total power blackout (loss of all thrusters)

For each situation, the system calculates the predicted path of the vessel, the maximum position and heading deviation, the equilibrium position and the maximum tension in the remaining lines during the transient period. The warning and alarm limits are not set by any code but by the operator (or the client under a WSOG agreement if the rig is drilling). The limits can be for position and heading deviation and for anchor line tension. The PM Online Consequence Analysis runs on all Operator Stations. The results are presented independently on each Operator Station. This means that the results can be slightly different from one Operator Station to another, but all are equally correct. The Operator Station in command will be responsible for issuing alarms.

### **Testing of the System**

Unlike a DP control system a thruster assist system is difficult to test in full scale as it requires a full mooring spread and anchor handlers as well as three days (at least) for the whole process unless it is at a drilling location. If at the drilling location then the rig is likely to be on hire and most oil companies would not wish to pay the day rate of the rig for testing equipment that the rig is responsible for providing in a fully tested and accepted operational condition. In the particular case of this rig, additional winches had been installed and the rig was to do work on moorings so it was considered prudent to prove the winches and take the additional time to fully test the thruster anchor assist system. The advantage this system gives the rig is that in some environmental conditions where the moorings are inadequate to stay on location the thrusters can be used so that moorings do not have to be picked up.

The rig was moored at a dummy location and a series of tests carried out firstly to cover the CAT (Customer Acceptance Tests) and secondly the FMEA (Failure Mode & Effect Analysis). A programme to efficiently include all these items and deploy and test the winches was drawn up. The CAT included the following.

- Winch inputs
- Moves within the mooring pattern
- Damping with thrusters
- Thruster failures
- Mooring line break with and without thrusters
- Consequence analysis

The FMEA tests included the following

- Testing damping after an major position disturbance
- Anchor position errors
- Anchor line parameter errors (stiffness, weight, length)
- Loss of data from one corner (two winches)
- Move and simulate anchor drag
- Tug to cause anchor drag
- Error in line length input
- Wrong heading input
- Wrong heading change
- Degraded position references
- Wrong position change
- Winch and SVC network failures

The tests showed that with care the system could perform well. The problems with the old thruster assist systems had been reduced significantly particularly by the use of calculated mooring line tensions instead of measured values. The comparison can be summarised as follows.

Old System	New System	Comment
Used Line Tensions	Uses Calculated Tensions	Great Improvement
Frequently Became Unstable	Less Opportunity to Become Unstable	Improvement
Need to start use before bad weather	Set up and can be left until bad weather	Improvement but still relies on operator understanding
Gets line break wrong and thereafter unstable	Line break not the aim but damping motion after	Improvement
Difficult to set up correctly	Difficult to set up correctly	Needs frequent use to get it right

### **Drive Off Position**

When testing had been stopped for the night the rig crew took the opportunity to check the length actually on board for one of the mooring lines using the winch and supply boats available.

In order to stay in position for the work boats and check the mooring line lengths full position control was selected (surge, sway and yaw), in effect DP that takes account of mooring line forces. In other words mixing DP with moorings.

No 7 line was slackened out slowly as can be seen by the green trace (tension) and the purple trace (line length). To compensate for the loss of this station keeping force the thruster's surge and sway forces can be seen to increase (light and dark brown traces).

There was a pause at a line length of about 1750m but just before this there was a jump in the tension. On board the vessel after this incident it was thought that the tension sensor had failed

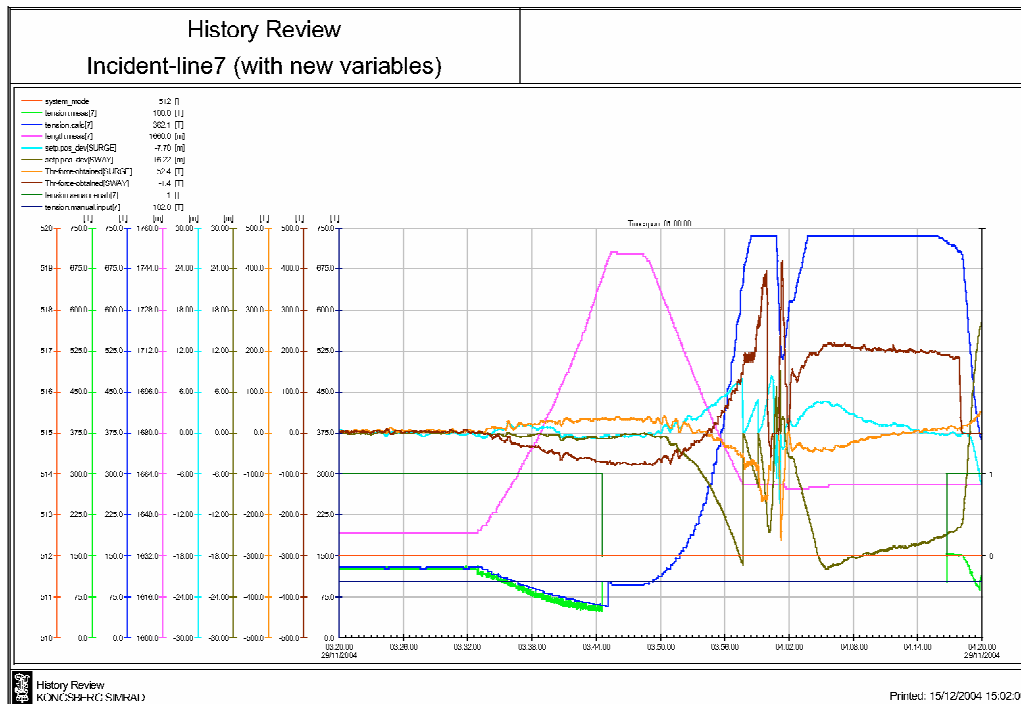
but some time after the incident it was found that the operator had disabled the sensor perhaps because it was giving an alarm for low tension (which was true).

Time	Event	Comment
03 43 58	Anchor 7 tension out of limits	“Anchor 7 tension out of limits” sounds several times due to noisy measurements (while running winch) operator specified limits (warning : 70.0T, alarm: 50.0T).
03 44 33	Anchor 7 tension sensor disabled. Manual tension value is 102.0T. Measured line length is 1741.0m	<b>Suspect</b> that the tension sensor was disabled (instead of disabling the alarm limits) to stop the “Anchor 7 tension out of limits” alarm.  When tension sensor is disabled, manual value is used instead. This manual value is also transferred to the logged “tension.meas[7]” variable. This caused the tension jump from approx. 50.0 T to 102.0T. (Initially this was wrongly assumed to be a jump in tension sensor measurements.) When the tension sensor is disabled the real tension sensor measurements is not logged. The calculated line tension is not affected by disabling tension sensor because calculated line tension is based on line length measurements (in addition to gyro, position and draught measurements).
03 45 09	Line 7 paid out to 1748.0m  Calculated anchor 7 tension jumps to 102.0T.	During this period the calculated line tension is updated due to line length but the chain is up and down. <b>Suspect</b> mooring model was reinitiated by operator. K-M believe this is the only way the calculated tension can jump 50t and be accepted. Normally any big jump in length, position and/or heading should automatically be rejected by the system (reject measurements, keep old value and report prediction error). During the close out test (test on mooring line 1) it was possible by manually reinitiating the mooring model to get the jump in the calculated tension.
04 16 40	Anchor 7 tension sensor enabled.	Measured tension values are logged again.

The above is the amended report of the incident trigger mechanism. Below is the results of the on board investigation.

Time	Event	Comment
03 32 58	Started paying out chain #7 winch In anchor handling mode Surge, sway and yaw control Damping Position Working supply vessel alongside starboard side Mooring Model using calculated tensions All thrusters selected	Working supply boat and slackening anchor chains at the same time made operators very keen to keep position.  Should not have been positioning with calculated tensions and full axis control  Two or three thrusters would have been adequate.
03 34 00	Thrusters start to compensate for loss of line tension of #7 mooring line	
03 44 34	The tension sensor for #7 mooring line failed (jumped) to 102t from about 50t..	The jump in tension was indicated on the SVC and on the mooring panel but there was no alarm or rejection of the data because of the jump
03 45 07	The TA control system accepted the new tension value and used it in the calculated line characteristic.	The operator should have placed all the mooring lines into “measured” rather than leave them in “calculated values.

Time	Event	Comment
03 45 24	Finished paying out #7 mooring line.	This measurement exercise was to avoid the risk of paying out to the bitter end by mistake
03 48 25	Started heaving in on #7 mooring line Rig stable on position	Tension increase in the calculated value started immediately the line length started to decrease
03 52 about	Discussion about tension between winch operator in winch cab and DPO on bridge	The tension jump while still paying out had gone unnoticed and it was not until the tension failed to change for some time that the winch operator asked the bridge what tension was showing on the TA system. The DPO read the 130t by looking at the calculated value. At this time there was thrust being used and a position excursion. This was the time to stop. The winch operator did this but then the decision to continue was made.
03 53 16	Calculated tension 200t	Operation should have been stopped
03 54 00	Thrusters at low force but start to ramp up	Operation should have been stopped
03 54 47	The calculated value of tension reached 300t	This tension is not real it is false. It is based on the line length and tension at the time of the sensor jump and the change in length since that time.
0355-0400	Several more operator errors	Operators not understanding the situation and worried about supply boat
04 00 32	Thrusters deselected	Moorings start to restore position
04 16 40	Tension sensor enabled	Recovery commences



There are several causes to this incident.

Firstly the vessel should not have been in position control, (mixing DP and Moorings) it would have been better to have been in damping for the operations in progress even with the boat alongside.

Secondly MEASURED anchor tension should have been used not CALCULATED.

Thirdly the tension sensor should not have been disabled, to stop the alarm.

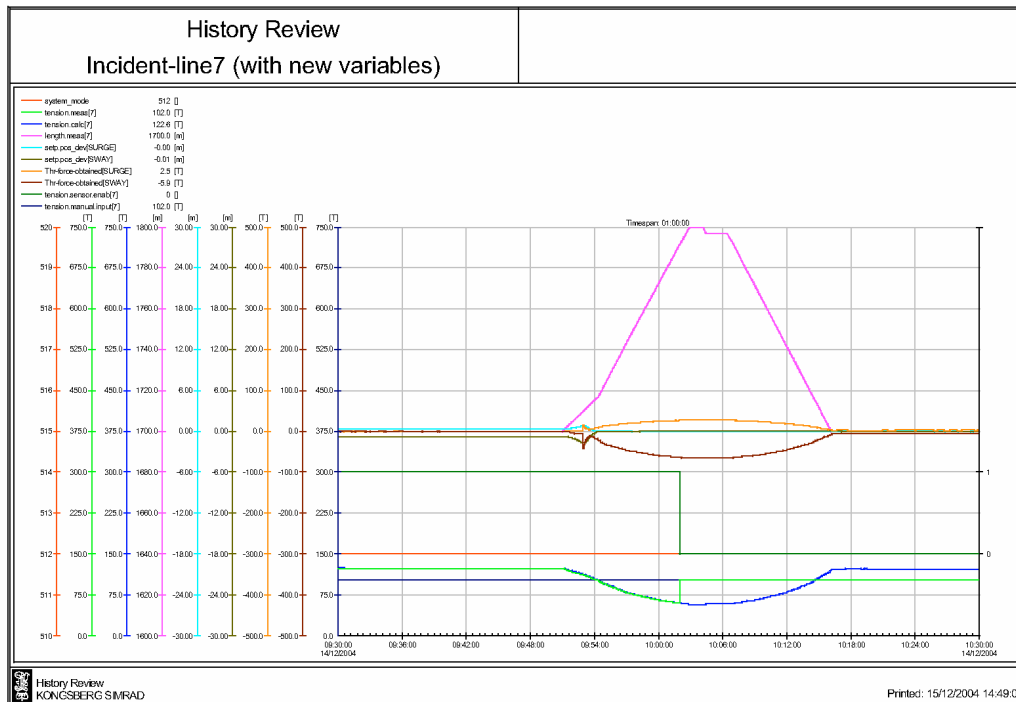
Finally the mooring model should not have been reinitiated with the wrong (manual input) tension.

All the above can be put to one cause inadequate training (or insufficient experience or both).

However perhaps the PM control system should not have ignored the length, tension mismatch. The PM system had enough relevant information and had this been used an alarm could have been given rather than a drive off.

There were no injuries or pollution just a few surprised people. The incident was closed out very quickly because there was also a Kongsberg History Station connected that had recorded all the relevant parameters. The later revelation that the tension sensor had not failed was a further lesson in history station use. However a failure of the sensor at this time would have had a similar effect.

The potential consequence of the incident in worst-case would have been collision with the supply boat and or the dragging of one or two anchors. However if the same circumstances took place while drilling/well testing with the anchors near pipe lines the effect could have been the loss and damage to the well and severe pollution, and substantial financial loss for all parties. This is because the loss of position was very fast, with the actual position loss underestimated and the thrusters were not stopped until the position loss was over 50.



The History Station's detailed information also enabled a good simulation of the same situation and a demonstration to all interested parties that the incident would not occur if any one of the causes are removed.

### **Conclusions**

Do not mix DP and moorings, TAM (Thruster Assisted Moorings) is different.

The latest PM system from Kongsberg is an improvement on their old APM systems.

TAM operators need more knowledge and training than that required for DP for them to use the system safely and to its full potential.

### **Acknowledgements**

Global Maritime acknowledges the will within the Statoil project to test thoroughly this system and the help of Kongsberg Maritime in these trials and the incident investigation.

