INTERNAL PRESENCE DETECTION OF OFFSHORE PRODUCTION SEPARATORS

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SUMMARY

Implementation of Condition Monitoring (CM) for offshore Oil and Gas (O&G) process equipment is important as it will enable early detection of developing failure conditions. This will in turn allow more time for planning and preparation of remedial actions, and will reduce revenue losses resulting from unnecessary and poorly coordinated maintenance actions. Also, implementation of Non-Intrusive Inspection (NII) methods will reduce personnel exposure to hazardous environment. This article is number two in a series of articles concerning CM of separators. Production separators constitute an important type of equipment related to O&G processing. Problem conditions that can occur inside the separator vessel and impact separation efficiency involve presence of scale, sand and other particles, emulsions, damaged/loose internal components, foreign objects, etc. Being able to detect and distinguish between such conditions is challenging. Therefore, methods for NII have been tested and developed in a separator laboratory built with the support from the Norwegian Center for Integrated Operations in the Petroleum Industry (IO Center: Collaboration between major international oil companies, suppliers and academia). Examples of methods are passive acoustics and gamma monitoring. The article presents obtained test results and suitability assessments of methods with respect to monitoring of internal separator conditions. The results support the feasibility of implementing the CM methods in order to optimise profit and ensure HSE (Health, Safety and Environment) levels.

Key Words: Separator, Internals, Maintenance, Failure diagnosis, Prognosis, Integrated Operations, Non-Intrusive Inspection (NII), Condition Monitoring (CM), Acoustic monitoring, Gamma scanning, E-maintenance

1 INTRODUCTION

The need to step up offshore O&G recovery while minimising costs and ensuring HSE, calls for improved effectiveness with respect to utilisation of available resources in offshore operations. A way to achieve these objectives will be through better interaction between interdependent offshore disciplines and development of dynamic organisations with advanced planning and change-handling capabilities. A key factor in this respect will be the use of CM data, giving early indications of developing failure conditions and resulting in better time for maintenance planning, coordination of logistics supply and execution of remedial actions. Production losses are costly, and through implementation of Condition Based Maintenance (CBM) one can expect fewer unnecessary maintenance shut-downs and reduced production down time in relation to maintenance actions. This will again have positive effects on system availability, operational costs and Life Cycle Profit (LCP) of the plant. In addition, use of NII methods will increase the HSE levels, e.g. when compared to internal visual inspections of pressure vessels where operators can be exposed to hazardous environments.

The present work focuses on NII methods for detection of internal separator conditions. Problem conditions affecting the quality of the separation process include presence of sand, scale, foreign objects, emulsions, interface foams and loose/detached internal components. Detection of these conditions represents a challenge according to operator companies involved in the IO Center (http://www.ntnu.no/iocenter), and it is important to be able to distinguish between the different conditions as they will require different corrective actions. To support research in this area a separator laboratory has been developed with the support from the IO Center. The article describes the laboratory set-up that has been used for testing throughout 2009, together with obtained test results and suitability assessments for methods with respect to monitoring of internal separator conditions. The tests performed in 2009 (Phase I) will be succeeded by more advanced tests in 2010, where the separator laboratory will be further expanded to include additional components and fluids. Finally, testing will be preformed on full-scale separators.

2 SEPARATOR TEST RIG

The Phase I laboratory set-up provides for controlled and stable test conditions. It has been designed with internal diameter of 1 m and overall length of 2 m. The wall thickness is 32 mm, and separator internal pressure is 1 bar. The separator volume is 1.6 m^3, and a pump installed in the flow loop can provide 0-40 m^3/h liquid flow inside the separator. A cyclone is installed on the inlet side. In order to compare results from CM instrumentation operating from various positions around and inside the separator, and to improve the operational conditions for the sensor systems, the separator is fitted with three horizontal and three vertical internal instrumentation tubes as illustrated in Figure 1. They are open ended stainless tubes of 60 mm inner diameter and 1.5mm wall thickness. On the inlet side they are located as close as possible to the cyclone. The tubes are arranged with flanges for mounting sensor system support equipment. A logical placement of the tubes will make it possible to get close to the most relevant areas inside the separator, such as places where e.g. accumulation of sand and scale is likely, or close to internal components that may suffer from loosening and detachment. The tubes represent a design proposal for new separators. In addition to getting close to relevant internal conditions, another advantage is that the tubes can be utilised in permanent scanning set-ups. A permanent set-up is feasible for remote execution from the control room or from an onshore center. Feasibility of installing instrumentation tubes should be further evaluated together with the vendor industry.

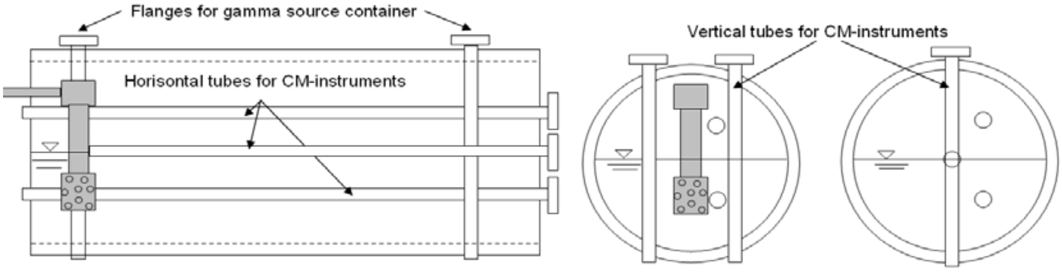

Figure 1: Phase I laboratory set-up with internal instrumentation tubes [3]

The Phase I laboratory can be used for tests with flow and for static test configurations. During flow tests, water is being circulated and air is taken from the ventilation system to produce two-phase flow. Different conditions can then be simulated, e.g. by placing sand in the vessel or cyclone, loosening of internal components and so on. Static tests can be performed by filling the separator with different phases and components as shown in Figure 2. Systems such as gamma transmission, active acoustic systems, neutron backscatter and Prompt Gamma Neutron Activation Analysis (PGNAA) can be tested and results compared directly based on their ability to detect what is inside the separator.

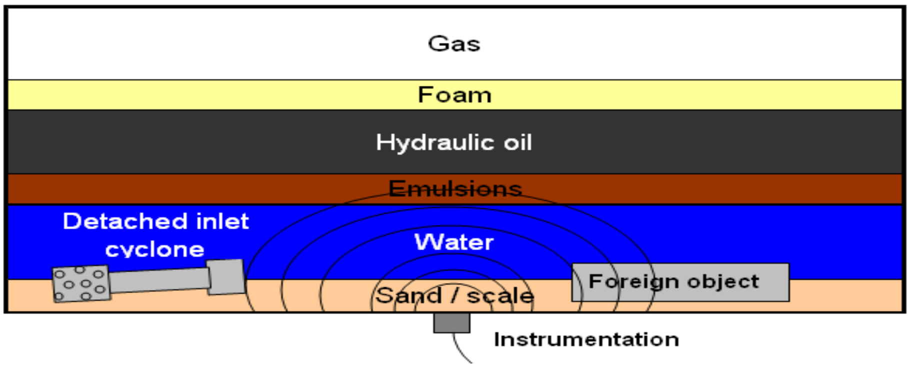

Figure 2: Principle behind static test. Different instrumentation can be fitted on the outside of the separator vessel or inside instrumentation tubes (tubes not indicated in this figure) for detection of the different phases and objects inside the separator.

3 CONDITION MONITORING METHODS FOR INTERNAL PRESENCE DETECTION

Two new methods for NII of separator internals CM are described here. The methods are under continuous development and refinement through experiments and analysis in the test rig described above. The two methods in question are based on passive acoustics and active gamma transmission, - both using sensors mounted on the steel surface of the separator or in steel tubes inside separator. None of the sensors are though in contact with the process medium.

3.1 Passive acoustic monitoring

Using acoustic sensors on the outside steel surface of the separator, noise and vibrations generated by stationary flow and incidents can be recorded and analysed. The result will depend on the condition of the internals, which may therefore be assessed by a suitable signal interpretation algorithm. The concept is entirely non-intrusive and suited for retrofit installation. Instrumentation tubes can be exploited for sensor-placement if available

Early tests of the passive acoustic concept were carried out at StatoilHydro's three phase flow loop at Herøya, Norway 2004-05. Noise and vibration generated by stationary flow and incidents was recorded and analysed, indicating that changes in flow conditions in three-phase flow lead to changes in the acoustic signature. It was concluded that the sensitivity to flow conditions indicated a similar sensitivity to the condition of the separator internals. The tests showed a significant level of background noise from adjacent machinery, propagating onto the separator shell through connected pipes and support structures. Discrimination between such noise and internal sources is important in order to avoid actions based on false alarms; background noise events. Such elimination can be based on source localization algorithms, exploiting several sensors distributed on the shell. This will also aid interpretation of signals from inside the separator. Two subsequent tests have been performed for separator internal condition monitoring. In [1] we presented results focusing on cyclone and proper mounting. Are we able to detect a situation where a cyclone loosens? Three situations were tested; 1) normal mounting, 2) a loose cyclone, 3) a detached cyclone (simulating a complete break-down, cyclone removed from inlet). Two different flow situations were used in all situations; 1) Steady flow and 2) Flow with slugs at inlet. Figure 3 indicates the flow for a normal situation with proper mounting (left) and an error condition with a detached cyclone. The different cyclone-conditions gave clearly different signal characteristics, visible in both time and frequency domain. Figure 4 shows example-results for a slug entering the separator inlet. We see that the reverberation time is much shorter with no cyclone present (right) It was concluded that the observed differences indicate that it is feasible to detect when a cyclone is no longer present. Several accelerometers in different positions contribute with different information. In particular, the use of internal inspection tubes simplifies the detection task. The vibration pattern in either cyclone-case is relatively complex, indicating that detection of defects may need to be based on *changes* relative to normal condition rather than a simple detection of events.

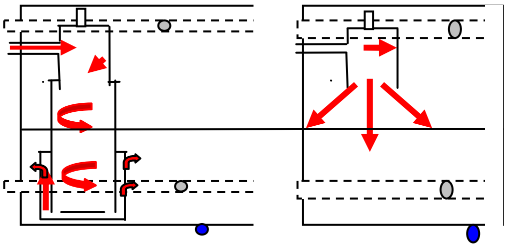

Figure 3: Indications of flow with and without an inlet cyclone

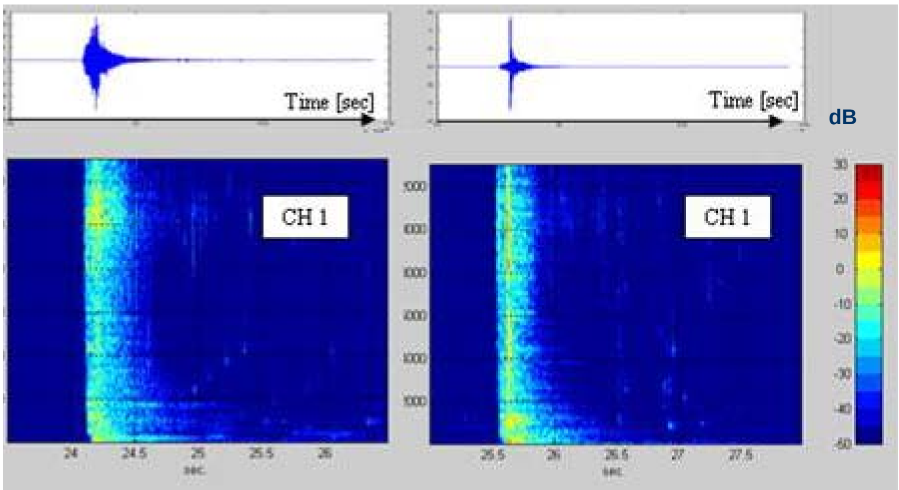

Figure 4: Time domain signature (upper) and spectrograms (lower) of acceleration signal from sensor on separator bottom. A slug is "shot" into the separator. Left pictures with cyclone present, right pictures no cyclone (see Figure 3). X-axis is time, in all figures; Y-axis is amplitude level in upper pictures, and frequency in lower pictures. The strength of the different frequencies is given as a colour code, in dB relative 1m/s^2. The slug is app. 40 cm long.

The present tests, as described in section 4.1, extend those in [1] by investigating:

a) Detection of sand in the cyclone.

b) Detection of objects falling down inside the separator, e.g. detachment of internal components

c) False alarms: Initial tests on vibrations from external sources propagating into the separator shell.

In test a) 1/3 of the cyclone was filled with sand, and acceleration on the separator wall and in the instrumentation tubes was recorded. The water flow varied from no flow to 21 m^3/hour. In test b) a light weight nut and a heavier shaft hit the bottom, the latter being covered with sand. In c) an electrodynamic shaker was connected to one of the pillars, generating vibrations controlled by a signal generator.

3.2 Gamma transmission measurements

The number of gamma particles in a mono energetic and parallel gamma ray decreases as it penetrates matter. When a gamma particle interacts with matter, its decrease in energy and/or change in direction are so large that it is no longer defined as a part of the ray. Due to its energy of 662 keV, the gamma ray used in the present work interacts with matter through photoelectric effect or Compton scattering. Photoelectric effect is absorption of a gamma particle by a bound electron. Compton scattering is interaction between a gamma particle and a free electron, where the gamma particle looses energy and changes direction.

Gamma transmission measurements are carried out by placing a gamma source and a gamma detector on opposite sides of the matter or process equipment to be investigated. The attenuation of the gamma ray utilized in the present work is mainly dependent on the density of the material between the source and the detector. Gamma transmission measurements performed in the present work are therefore density measurements.

When we measure the density between the source and the detector, we want to detect gamma particles that have moved directly from the source to the detector without any interaction. We do not want to include Compton scattered gamma particles, because they may not have moved through the material between the source and the detector. There are two common ways to avoid Compton scattered gamma particles: collimation and energy discrimination. Collimation requires massive materials around the source and/or the detector to absorb gamma particles that have not moved directly from the source to the detector. Energy discrimination requires an energy sensitive detection system that only accepts gamma particles with the same energy as emitted from the source. This is an effective method to avoid Compton scattered gamma particles. A negative side effect is that it rejects gamma particles that do move directly from the source to the detector without interaction, but interacts with the detector by Compton scattering instead of the photoelectric effect.

Gamma radiation is highly penetrating. It is therefore well suited for NII of massive process equipment. Gamma transmission measurements is a well-proven method, and commonly used for industrial process equipment [2]. Stationary and permanently installed gamma transmission gauges are used for continuous monitoring of interface levels inside separators, while gamma scanning is used for troubleshooting of separators. Gamma scanning is performed by placing source and detector on opposite sides of the separator and moving them as a unit along the separator.

4 TEST RESULTS

4.1 Passive acoustic monitoring

In the tests reported here 6 accelerometers were glued to the separator wall or attached to the wall of the internal tubes.

a) Sand in the cyclone.

With sand in the cyclone we visually observed, through a window in the separator wall, that the fluid pushed the sand up against the cyclone wall. We were also able to hear the grains hit the wall through the background flow noise. This sound is seen as vertical stripes in a spectrogram, as shown in Figure 5. Here the right part is recorded with sand in the cyclone, and the left part without. The flow is pure water at 7m^3/h. The figure also shows a photo of the cyclone (top view) with sand. An algorithm that automatically detects such stripes can be developed quite straightforwardly, by conventional image processing techniques. In analogy with the test results, detection of other loose objects in a cyclone certainly seems feasible.

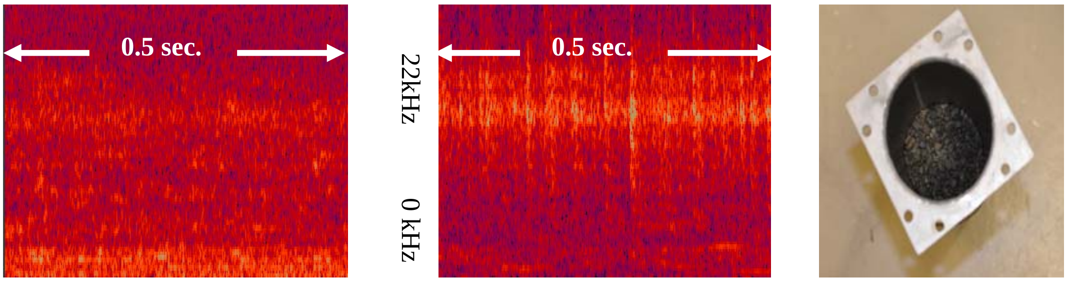

Figure 5: Spectrogram of sand (grains) hitting the cyclone wall. To the left there is no sand in cyclone, to the right 1/3 of cyclone is filled with sand (cyclone shown in picture to the right). The vertical axis is frequency, the horizontal is time.

b) Falling objects inside the separator.

Detection of objects hitting the separator bottom was tested with sand (sediment) covering the bottom. This is a more challenging case than a clean separator wall. A moderate background flow was also present, generating flow noise that masked weak signals. Light weight metal nuts were dropped from the gas phase, and a 15 kg metal shaft standing vertically on the sand was tipped over.

The nut was not detected as it hit the sand, due to masking by the flow noise (14m^3/h). It was, however, possible to detect it hitting the water surface. This appeared as a distinct short increase in power for frequencies up to 500 Hz.

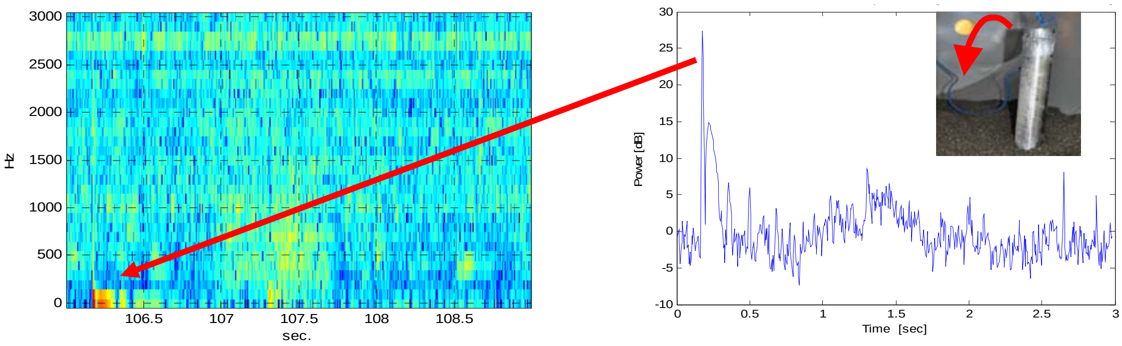

Figure 6: Spectrogram (left) and time sequence (right) of acceleration measured on bottom wall when a shaft (photo to the right) of 15 kg is tipped over into the sand covered bottom. The water flow is 14m^3/h with no air. In the spectrogram the strength of the different frequency components (in dB) are coded in colour, while the amplitude is given directly as y-value to the right.

The observation illustrates the sensitivity of the sensor concept, but can hardly be expected to appear in a full scale hydrocarbon separator due to higher background levels and often a foam covered liquid surface. When the 15 kg shaft turned over into the sand, the same increase in power for low frequencies was observed. This is shown in

Figure 6. The right part of the figure shows the acceleration as a function of time, showing a clear signature with a pronounced peak lasting some tens of a millisecond. This is found as increased power for frequencies up to 250 Hz in the left figure. This is seen in all sensor positions. The tests clearly support the feasibility of detecting hits against a sediment covered separator wall. A remaining uncertainty is the background noise level of full scale separators. This, together with the softness and thickness of the sediments, determine the impact energy necessary for detection. Large objects like full scale cyclones are very likely to be detectable in any case.

c) False alarms

In a monitoring system it is important to minimize the probability of false alarms. In passive acoustic monitoring the most likely cause of false alarms are vibrations from external sources, propagating onto the separator shell through connected pipework and the separator support. These signals will come and go, and are typically dominated by low frequency components. As already indicated in section 3.1, discrimination between such signals and those due to sources inside the separator can be based on *source localization.* This relies on the use of several sensors distributed on the separator shell and, if present, in the instrumentation tube.

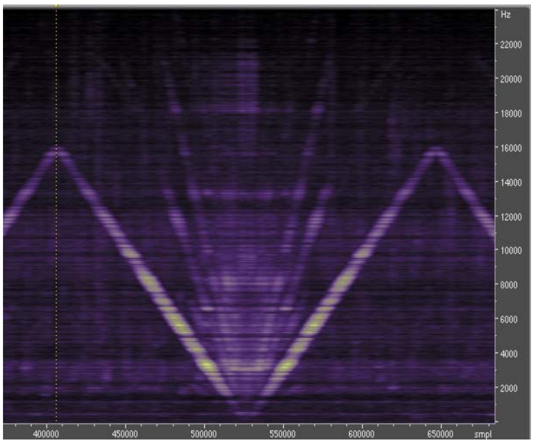

Figure 7: Spectrogram of a sine-sweep signal, recorded by accelerometer on separator wall. The brush-like feature is harmonic components of the sine-sweep, due to nonlinearity in the shaker-response.

Initial tests have been carried out in order to study the feasibility of using distributed sensors to discriminate between separator-internal and external sources. An electro dynamical shaker was connected to one separator pillar at the floor, feeding the pillar with a sine-sweep from 70 Hz to 16 kHz. The signal is shown in Figure 7, as picked up by an accelerometer on the separator shell. The water flow rate varied from 2 to 14m^3/h, the gas from 0 to 5 gram/sec. This provided for large variations in signal to noise ratios.

A simple correlation analysis was performed between signals picked up at different locations on the surface. The processing showed clear similarities between the signals, but did not give time propagation delays consistently increasing with distance from the pillar. Consistently increasing delays were, however, found by manual inspection of the spectrograms. More sophisticated analyses are part of future work. This work will also include sensor placement strategies, explicitly focusing on the localization task. At present we conclude that source location is non-trivial, but that the visual inspection results are positive indications with respect to feasibility of the approach.

4.2 Gamma scanning

Two gamma scans of the separator floor have been performed. In the first scan, foreign objects like sand, soft scale and a metal piece were placed on the separator floor. A sketch and a picture of the set-up are shown in Figure 8. The sand and the scale were kept in place by an aluminium frame with a height of 20 cm. The scan was performed by moving source and detector stepwise along the separator. A 2” NaI(Tl) detector was moved through an instrumentation tube below the separator and a ^{137}Cs source of 370 MBq was moved through a parallel instrumentation tube inside the separator. The instrumentation tube for the source was not centred (the horizontal tube to the left in the picture in Figure 1 was used). A measurement was performed for each second centimetre. Position 0 was defined at the inside of the separator endplate where the scan started (at the left side of the sketch and at the back of the picture in Figure 8).

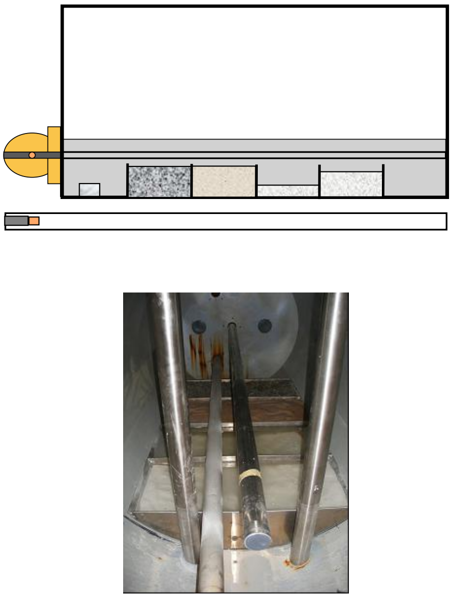

Figure 8: A sketch of the experimental set-up (upper) and picture of separator internals (lower) during the first scan

A steel cylinder (15 cm in diameter and 8 cm high) was placed at position 14 cm, 20 cm sand was placed in position 34 to 67 cm, 20 cm of another type of sand was placed in position 67 to 100 cm, 10 cm of soft scale was placed in position 100 to 133 cm and 20 cm soft scale was placed in position 133 to 166 cm. The separator was then filled with 30 cm of water. The water covered the instrumentation tube used for the source. Sand and scale were compressed when the water was added, resulting in reduced sand and scale heights. At position 27 cm there was a plastic plug in the separator floor where a vertical instrumentation tube can be mounted. In the second scan, sand and scale were removed and a vertical instrumentation tube was inserted at position 27 cm. The aluminium frame was still in place and the water height was the same as in the first scan. This would be the background scan in a real case, and any later deviations from this result will indicate a change, for instance presence of sand, scale or other foreign objects, or missing internals.

A recently developed detection system with 256 energy channels was used. The energy spectrum measured in position 173.5 cm from the first scan, is shown in Figure 9. The channel number on the abscissa is proportional to the energy measured by the detector, i.e. the energy deposited in the detector due to interaction with a gamma particle. The ordinate shows the number of detections in the different channels. ^{137}Cs emits gamma particles with energy of 662 keV. When they move directly from the source to the detector without any interaction, and interact with the detector through photoelectric effect, they build up the 662 keV photo peak that is clearly seen with centre in channel 155. Compton scattered gamma particles, scattered either in the detector or elsewhere, are registered in lower channels. Due to drift in the detection system, the position of the photo peak was not constant during the two scans.

A gamma scan gives detector response as a function of position. The detector response is given by counting rate, i.e. number of detected gamma particles per unit time. Since we have an energy sensitive detection system, we may accept only gamma particles detected within specific energy intervals (or intervals of channels). We have chosen to accept either all detected events (gross), or only gamma events in the photo peak. Due to drift of the detection system, we have adjusted the interval of channels, called region of interest (ROI), to the actual measurement. The centre of the ROI was moved according to the shift of the photo peak and the number of channels included in the ROI has been proportional to the position of the peak.

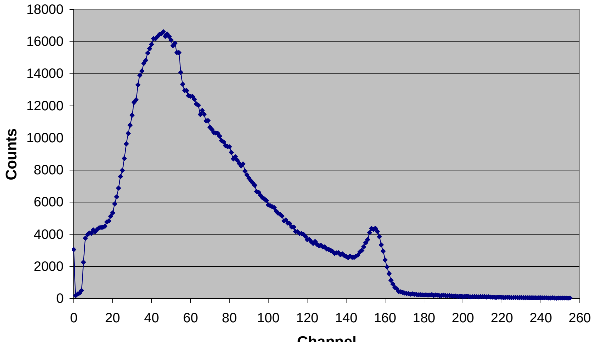

Figure 9: Measured energy spectrum with the 2” NaI(Tl) detector and 256 energy channels MCA of the ^{137}Cs source in position 173.5 cm during the first scan

The results are presented in Figure 10. Low count rate means high density and vice versa. The blue lines (Scan) are the results from the scan with foreign objects present. The purple lines (Background) are the results from the scan without foreign objects present. Including all detected gamma particles gives the figure to the left, while the figure to the right shows the results when we only take the events in the photo peak into consideration. The counting time was 60 seconds at each position in the first scan (Scan) and 10 seconds at each position in the second scan (Background).

The count rates at position 0 are low because the detector was partly shielded by the separator flange. The count rates increase when a larger detector volume gets exposed to the source. At position 27 cm the count rates are high since this is the position where a vertical instrumentation tube can be mounted. This effect is different for the two scans because the instrumentation tube was only present in the background scan.

The scan with foreign objects present shows clearly the steel cylinder and the transition from one medium to another. Scanning without foreign objects shows the location of the thin walls of the aluminium frame used to separate sand and scale compartments. (The reason why the positions of these walls are not identical in the two scans is that the aluminium frame had slightly moved when we removed sand and scale.)

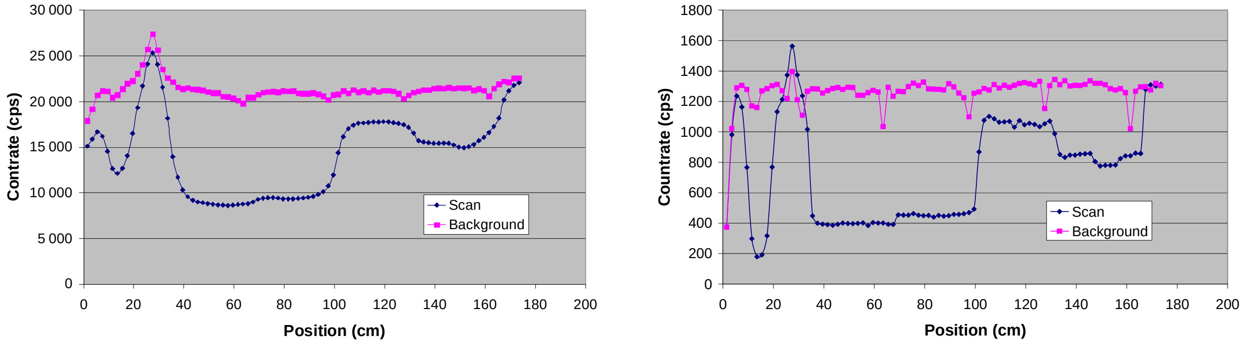

Figure 10: Results from the scan with foreign objects present (Scan) and from the scan without foreign objects present (Background). The figure to the left shows the gross count rates and the figure to the right shows the photo peak count rates.

The curves produced with photo peak count rates show larger statistical fluctuations due to fewer counts than the curves produced with gross count rates. However, the results obtained with photo peak count rates are superior the results obtained with gross count rates because of better spatial resolution resulting in sharper transitions between the compartments. It was essential to adjust the ROI according to the drift in the detector system to obtain the results presented in Figure 10.

5 DISCUSSION AND CONCLUSIONS

The work done until now shows that we can successfully detect a number of the indicated internal conditions in the Phase I laboratory. Using passive acoustics sensors we can detect loose or detached inlet cyclone, falling objects in sand, sand or foreign objects inside the cyclone. The sensors can be retrofitted and the method is suited for automatic continuous supervision and automatic diagnosis based on automatic pattern recognition in time and frequency domain.

Gamma scanning of the bottom of the separator is well suited for detection of sand, scale, other foreign objects and missing internals. Instrumentation tubes inside the separator are necessary to make this method attractive. The spatial resolution is greatly improved by using an energy sensitive detection system and energy discrimination which rejects events caused by Compton scattering and only takes events in the photo peak into consideration. This can be taken care of by the software by registration of the photo peak position, and either adjust the high voltage in the detector system to keep the position of the photo peak constant, or adjust the ROI. There exist stationary gamma transmission measurement systems designed to detect build-up of sand in separators. However, a scanning system can measure the whole length of the separator to search for foreign objects and missing internals. Further, the scanning profile may be important to distinguish between sand and other foreign objects.

NII methods for separator internal presence detection should be implemented in order to optimise production efficiency and allowing timely planning for remedial actions and coordination of available resources for necessary maintenance actions.

6 FURTHER WORK

Testing will take place in different phases. The Phase I laboratory has been used for testing throughout 2009. Some tests using gamma scanning remain to be carried out in the Phase I laboratory, which will involve level measurements, presence detection of inlet cyclone and measurements of vertical liquid distribution in the inlet cyclone. The laboratory will be further expanded in 2010 into the more advanced Phase II laboratory, where additional internal conditions, fluids and components will be introduced. Flexibility will be ensured so that any desired test configuration of the Phase I or Phase II can be utilised at a later point in time. At last, in Phase III, the project aims to perform full scale tests in cooperation with stakeholders in the IO Center.

7 REFERENCES

1 Brurok T, Hennie E, Reinen TA, Berg T, Haugan A, Opel K, Hoffmann M, Thunem H. (2009) Internal presence detection of offshore production separators. Proc. COMADEM 2009.

2 Geir Anton Johansen and Peter Jackson. Radioisotope Gauges for Industrial Process Measurements.John Wiley & Sons, Ltd. (2004).

2 Hennie E, Brurok T. (2009) Phase I Separator Laboratory – Design Report. IO Center report 260082.12.01.

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