Appendix F:

Summary of Aker Solutions observations and assessments on the bilge system functionality and design

APPENDIX F – SUMMARY OF AKER SOLUTIONS OBSERVATIONS AND ASSESSMENTS ON THE BILGE SYSTEN FUNCTIONALITY AND DESIGN

F.1 Introduction

NSIA has used Aker Solutions as assistance for quality assurance and professional expertise to assess various issues related to the frigate's bilge system.

Aker Solutions scope of work was to assess the bilge system towards the design regulations from the time of construction, hence all references to "regulations" is only towards the design regulations and not towards todays regulations.

The following is what Aker Solutions observed and assessed prior to, during and after the full-scale test of the main bilge system and isn't necessarily to be regarded as final as actual test data haven't been or is available to Aker Solutions today.

Further follows a general summary of Aker Solutions observations from drawings and documents regarding the vacuum bilge system design on the vessel and on the general principles for functional design for such systems seen towards the relevant requirements in regulations on this topic.

F.2 Observations from the pre-test work

F.2.1 Design documentation

After going through the design documentation and regulatory requirements from the time of construction no findings, unusual methods or descriptions for this type of system was found. The design documentation is typical for the ship industry in format and content and lists design parameters and choices made in a structured and easily understandable manner. Hence no design justifications, fulfilment of functional requirements, probability assessments or documentation of if the bilge system is fit for purpose in the form of calculations or simulations is included.

F.2.2 Test procedure

No observations or comments was identified with respect to the test procedure or the pre-test meeting. The test procedure was well defined and suited for conducting the test with the required quality. Some minor recommendations were presented by the pre-test meeting attendees and implemented in the final test procedure. Valves and pipes in the bilge system was prepared by washing and flushing, and by carrying out the pre-defined maintenance activities for the bilge system.

F.2.3 Accept criteria and purpose of the test

The accept criteria for the test was defined to be the regulatory requirements at the time of construction. This is slightly less stringent than what was defined in the hull building specification from the yard.
The purpose of the test was to conduct a full-scale test of the bilge system capacity and to uncover any deficiencies. The required degree of precision in the measurements during the test and a more detailed accept criterion was not defined beyond the regulatory requirements.

F.3 Observations from the full-scale test of the bilge eductor system

F.3.1 From the capacity test

Filling of water in the test area was done in a space without a constant waterline area such that depth measurements doesn't linearly represents a change in volume. A mechanical volume counter with a listed precision of 2% was used. Aker Solutions is of the opinion that this method is sufficient for the purpose of the test as long as the precision of the measurements are considered in the final evaluation.

Preparation and start-up of the seawater pumps and valve initialisation in the bilge system was tried from the IPMS according to the test procedure. It was observed that the sectionalisation valves returned to the wrong state even with repeated attempts at direct valve control from IPMS. Then attempts at controlling the valves directly from the actuator control boxes were made with the same results. Manual opening/closing at the valve was then carried out to reset the end-switches to allow remote operation from IPMS. Here it was observed that some valves wouldn't reset and allow for remote operation. Then the valves were put in manual mode and set in the correct position for the actual test to be run.

This is the most serious observation from the test as it could indicate that the control system doesn't work as intended and manual access to the valves could be unavailable during a water ingress situation which would lead to bilge system unavailability or significantly degrade the system performance. A recommendation to further assess the system technically and to review the current maintenance procedures applicability for avoiding and detecting this type of error state should be given to the owner of the facility.

It was observed a discrepancy when reading the vacuum and drive media pressures at the eductors from IPMS and locally in the room making it impossible to establish whether the system operates as intended. It was also observed that some local manometers for drive media pressure was defect and others showed physically impossible values. This is a quite serious observation which could prevent the detection of a fault or misinterpreting the actual error state. A recommendation to the owner of the facility on verification, correction and/or calibration to be done regularly as part of the operation and readiness procedures and also it should be included in the maintenance procedures to ensure the system monitoring to be reliable, should be given.

No negative observation was made to the measurements of the bilge systems capacities. The participating personnel's knowledge and competency must be said to be exemplary for the full-scale test. Representatives from the construction yard, class authorities, operators and controlling personnel was present the whole time and contributed positively to the test and that it was doable with a sufficient number of scenarios and measurements.

Only very small changes to trim and heel was observed during the test. As they were very small and infrequent it must be said that this is within the practically controllable limits. It could affect the calculations of degree of filling slightly, but not enough to change the outcome of the test. As freshwater was used for the filling to avoid any degradation of equipment exposed to the test, one needs to correct for the density which will be approx. a reduction of 2-2.5% for high flowrates in the eductor system.

It was observed too low bilge rates according to the test's pre-defined goal and specification. The flowrate reduction was large enough to conclude that it was not according to the level of precision and uncertainty in the test. This is a serious observation as it is a deviation towards the owners expectations to a safety critical system. It is important to emphasize that the system has not failed but delivers too low flowrates. This opens for a discussion on the degree of degradation/failure which needs to be concluded prior to a conclusion on real associated risk for the identified problem. Again, it is assumed that this is included in the assessment on the test results in the test documentation.

F.3.2 Changes to the test procedure done during and after completion of the test

Some of the scenarios in the test was postponed and some were done in a different order than planned due to time constraints for the test. However, this was not considered to affect the test negatively as the high and low scenarios was kept and only the intermittent tests were postponed simplifying the test programme. Each individual eductor's capacity was confirmed by achieving stable flowrates without significant variation in each individual test scenario which was completed.

A scenario was added to investigate the effect of improved suction conditions by manually opening an extra parallel suction line but without any significant observed improvement. This provided valuable information on that the system is not limited by the suction conditions in a full capacity test (6 eductors). One scenario with 1 eductor out of service (5 out of 6 eductors ran) was also ran with the same result as the full capacity scenario. This may indicate that the system downstream is the constraining factor with a too high backpressure in a full capacity scenario. A recommendation on further assessments in this part of the system with simulations and calculations should be given to the facility owner.

F.3.3 Outstanding test elements

Based on the general observations during the test it is considered that the outstanding parts of the test is not likely to change the results if they were to be carried out later. It would however ensure a higher degree of precision and reliability of the test results and possibly better reflect each single eductor's condition.

F.4 Assessments regarding the test

F.4.1 Bilge system functionality

The bilge system’s availability and functionality are governed by several parameters. Capacity, monitoring, remote control and configuration. Independently of if the capacity is sufficient or not the bilge system could fail if monitoring and/or remote control fails. The systems functionality must be assessed as a whole for any safety evaluations on availability.

F.4.2 Criticality of the observations

The regulatory requirements to the bilge capacity are formulated as equipment dimensioning requirements and not operational requirements which have to be fulfilled in a defined situation. Hence the regulatory requirements purpose is to provide the designer and the construction yard a parameter to choose and arrange the actual equipment based on the regulatory issuing body finds as an acceptable capacity. Based on this fact, it is not possible to conclude that the given regulatory requirements must be met to achieve a sufficient level of safety.

One may conclude on that it is required with further assessments on which actual safety consequences it has too not meet the regulatory requirements. This should be done together with the regulatory body to ensure a correct quantitative understanding of the deviation in flow rates which was observed.

The observations on monitoring of the operational parameters vacuum and drive media pressure, is that one has observed a discrepancy between IPMS and local manometers without means to decide which reading is correct.

This is critical regarding the evaluation of the bilge system state in an operational situation with water ingress. It was also observed defect manometers and readings of negative vacuum which is a physical impossibility.

The observations on missing remote control from IPMS of sectionalisation valves in the seawater system is critical in regard of been able to quickly carry out segregation and set-up of the system in an operational situation with water ingress. This is especially critical when seen in conjunction with the observations on malfunctioning local control from the actuator control cabinets.

Together these observations are highly critical issues if an operational situation with water ingress should occur as only manual operation on the valves themselves is left and the valves may be unavailable in a compartment flooded with water.

When seen together it becomes clear that the bilge system’s actual condition and its’ availability is a very vulnerable area and that the total system including operational and preventive measures doesn’t seem to be robust enough to claim that the system is fit for purpose - at least as the system was presented during the full scale test.

F.4.3 The intentions of the design regulations

The used design regulations are typical for the maritime ship industry which focuses on serial production and experience-based design. For the very specialised and costly vessels as looked at here, one should consider recommending verifications on top of the prescriptive design principals as described in the design regulations. By utilizing functional requirements to establish the design parameters for the actual vessel in question and for its’ actual intended use, one will achieve the desired robustness instead of a robustness based on earlier times experiences alone. As a minimum one should consider using methods as HAZID and HOZOP (both operational and system design) based on f.i. ISO norm or other applicable standards. This is a methodology which have been an industry practice in Norway and other countries the last 20 years in offshore- and petrochemical industry. Then one would attain a better understanding of the actual risk picture and the actual vessels suitability or state of “fit for purpose”.

F.4.4 Preliminary conclusions and recommendations

It is strongly recommended to continue the work with identifying limit factors for the bilge system to be able to understand the consequences of the different mitigating measures being considered.

System and capacity simulations and risk evaluations of the reel required demand for the bilge system should be conducted prior to any technical changes are implemented.

It is important to highlight that 3 categories of observations are made; capacity, monitoring and remote control. The assessments on the insufficient bilge rate capacity real impact doesn’t affect the findings on monitoring and remote control. All 3 categories of observations are important, and work should be progressed further on them to prevent failures in bilge systems in real operational situations in the future for similar vessels.

It is also recommended that the issuing body of the design regulations should be contacted to clarify the intention and the criticality of the requirements which is not met.

It is common that observations on topics covering preventing maintenance and inspection routines, especially on safety critical equipment, is an indication on a more general potential for deviations on other areas or systems with similar routines for maintenance and inspection. Hence it is common practice in the industry to conduct a screening or random test on these areas and systems to check whether if the situation is acceptable or if a potential for similar undiscovered issues exists.

F.5 Principles for vacuum bilge systems

F.5.1 Bilge

Bilge suction is generally done from the lowest available elevation in each compartment on a ship. As ship structures have extensive structural elements and rounded shapes of the hull, any suction must be led down into tight congested areas with poor accessibility. Hence it is mostly found appropriate to use suction pumps and/or eductor-based suction systems to achieve maintenance access to the mechanical equipment.

F.5.2 Driving medium

Suction pumps have a limitation in that they must be primed with a fluid to get a reliable start-up of the pump as it is unfeasible to design and produce screw-type pumps with sufficient flow and capacity without introducing a frequent and difficult maintenance regime. This type of pump is also vulnerable for fouling with degrading of performance. Hence often a combination of vacuum pumps/eductors and ordinary bilge pumps is used to ensure priming of the pump.

Pure eductor-based systems are also common in use and they are very robust towards changes in the medium to be evacuated and to fouling, and they are very easy to arrange wrt. design and maintenance. When you expect fluid/gas slugs, eductor-based systems are far more tolerant than traditional pump designs.

F.5.3 Available energy and potential

Vacuum systems has relatively little available energy and pressure potential compared to standard centrifugal pumps. The theoretical pressure potential is only 1 bar (100% vacuum) compared to typically 10-15bar in a standard pump system based on positive pressure lift. In practice you have less than 1 bar available potential as it is always some losses in the system and for distributed multiple eductor systems you often end up in a dynamic hydraulic imbalance which is difficult to predict and to balance out in the design.

F.6 Aker solutions Observations from the documentation of the eductor-based bilge system

F.6.1 Pipe dimensions

Pipe dimensions in the bilge system is typically based on assumptions around acceptable flow velocities defined in class rules, design standards, regulations and experience from similar systems.

The challenge with this is that the experience largely seems to be from positive pressure lift systems where available lift is 10-15x what you can achieve in a vacuum suction lift system. Hence one is quickly at the limitations of a vacuum lift system when multiple valves and pipe bends is used when one is allowing a high flow velocity as is normal in a positive pressure lift system.

The construction yard have conducted simplified calculations on flow velocities which even though they are within the allowed velocity rang has a far higher flow velocity than one normally would recommend for this duty in other types of ships, even in applications where the bilge systems have the lowest criticality, due to the pressure losses one would get.

F.6.2 Flow velocities

The flow velocities in the bilge system is based on the design regulations without further consideration if it is acceptable or not for the vacuum lift part of the pipe design.

Based on other types of eductor based vacuum systems such as stripping systems for ballast water tanks, one have seen that it is required to keep the flow velocity below ~3m/s where there are elements in the pipe design introducing significant pressure drops - as in areas with many pipe bends, small pipe diameters and many valves.

F.6.3 Analyses to document a pipe systems' suitability

Todays the standard way to document a pipe systems' suitability for a given duty is to run a 1-dimensional flow simulation in special software made for this purpose (PIPENET Transient, PIPE FLOW Expert etc.). Running transient simulations for complex facilities as f.ex. fire-water distribution systems has become an industry standard in all offshore engineering.

When addressing generic bilge system designs today in such software, one finds that a degradation of 30-40% in capacity in complex systems is to be expected when using the regulations maximum allowable flow velocity.

The used pipe lengths, number of valves, chosen pipe diameter and the complex system topology with a very high number of operational configurations dictates that a more thorough documentation of the systems real available capacity is required to ensure that the system is suited for the duty and that it is robust enough to handle expected degradations.

It may appear as a bit unexpected that the design rules don't ask for further documentation for complex systems, especially when based on vacuum lift principles, and that it doesn't differentiate between vacuum- and pressure-lift systems in its prescriptive ways.

F.6.4 Bilge system functionality

It could appear to be a weakness in maritime design rules that no requirements to achieve the required system capacity even if one stays within each single technical requirement as f.ex. maximum allowable flow velocity. To not take a systems topological complexity and obstructions into consideration makes this way of defining design requirements inappropriate as you have no way of knowing if the system as a whole works as intended.

F.6.5 Criticality of the observations

As the design regulations are formulated and how we observe construction yards design practice, leads to a need for the need for elevating the bilge systems criticality and it also forces the owner of the vessel to on own initiative to put forward additional requirements in contractual specifications to get a bilge system with sufficient capacity and level of safety.

For similar constructions to be built in the future Aker Solutions recommends that additional requirements to calculations and documentation of suitability by demanding flow analysis, full-scale testing (or other similar tests) documenting that actual performance for the completed system.

For the maritime and offshore industry, additional requirements going out over the minimum requirements in the design regulations have been common for most construction contracts on all areas which the owner regards as especially critical or to be important from other reasons. This is done in practice by establishing a more detailed building specification than what is required in the design regulations and is included as an attachment in the construction contract. This then becomes governing for the design of the facility and for planning testing to be accomplished prior to acceptance of the vessel. This either requires a competent 3. Party to assist in the establishment of the building specification or a significant own competency within the vessel owner's organisation. This is a topic which have been and will be subject for discussions as it may affect the commercial conditions significantly for a construction contract.

F.7 Conclusions and recommendations

Aker Solutions strongly recommends continuing the work with identifying limitating factors for the bilge system to be able to identify the actual effect of any mitigating measures being considered. System and capacity simulations, risk evaluations of the actual requirements for the bilge system should be carried out prior to any technical changes is implemented for other vessels of the same class.

Once more it is recommended that the applied design regulation’s owners and the vessels technical authority should be consulted to clarify the design intentions regarding criticality for the design requirements which is not met. In particular the design requirements for systems with a vacuum suction principle, where system complexity or system criticality is important for the vessels operational capacities.