TOWED ARRAY TECHNOLOGY: DEVELOPMENT FOR A BETTER SONAR SYSTEM PERFORMANCE

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Abstract: In present missions of submarines, the detection of hostile targets is one of the main objectives. To achieve these objectives modern submarines are well equipped with sonar sensors and signal processing units for all acoustical frequency ranges. The detection and analysis of silent or distant targets is the main task of towed array systems. Towed arrays have their advantages in the low frequency range, where acoustic signals are propagating with low attenuation together with a significant reduction of platform noise. The qualities, development- and production process of ATLAS towed arrays is the topic of the paper.

Keywords: Towed array sonar; flow noise; CFD; explicit FEM; turbulent boundary layer; numerical simulation; test facilities; platform noise: winch system; combat system; sonar performance; tactical situation

INTRODUCTION

The development of a Towed Array Sonar (TAS) as a low-frequency detection component of the sonar equipment of a submarine is a very complex task, which is to be described below under system-related aspects. In this context, besides the acoustic requirements, which are very closely interlinked with the properties of the materials, also the electrical and electronic pre-conditions must be fulfilled in order to be able to construct a towed array with digital data transfer. As a TAS is not an array that is permanently mounted on the hull of the submarine, the running behaviour of the array during operation is also of great importance. Here important findings can be gained with numerical simulation methods, not only for the launching process but also for the operative parameter conditions e. g. while using Target
Motion Analysis (TMA). To round out the system-related aspects, attention is drawn to the necessary handling equipment in the form of a TAS-WHS (Winch Handling System), for which new solutions had to be found e.g. for launching the array through flushing out. Here too, the approaches adopted while applying CAE methods are shown within the framework of a system review.

To get an appraisal of the results of the towed array sonar concerning the theoretical detection ranges, ATLAS ELEKTRONIK developed a new tactical decision support tool SPIRIT® (Sonar Performance Information Range and Integration Tool). Instead of a three dimensional performance picture which is hard to quantify the actual results will be presented as a vertical and horizontal cut on two sonar consoles at the same time.

**DEVELOPMENT OF A TAS-SYSTEM**

**System Components**

A TAS system consists of the following main components:

- Array section (HF, MF, LF): length approx. 150 m
- One Vibration Insulation module each at the front end and at the rear end of the array section: length 20 m
- Towing cable approx. 200 m
- Tail rope approx. = 30 m
- Winch on board of the submarine for handling the array including launching device and cable cutter in case of emergency
- Signal processing on board; integrated into the signal processing of other sonar sensors (e.g. Flank Array Sonar – FAS).

Altogether a compact system is thus defined that provides a substantial gain in detection performance above all in the low-frequency range (cf section “Performance”). However it must be pointed out that not only performance but also the system components must be carefully matched in order to achieve very good overall performance. This harmonisation has been carried out not only on the basis of extensive trials and test steps, but also with the recently available numerical simulation methods (FEM, CFD = Computational Fluid Dynamics).

![Fig. 1: Schematic structure of the hydrophone section](image)

![Fig. 2: Skeleton of the hydrophone section](image)

The fundamental structure of a Towed Array hydrophone section is illustrated in a schematic display in Fig. 1. Located inside a hose (diameter D = 50 mm) is a skeleton made up of mouldings that alternately contain hydrophone and electronic components. The mouldings are connected to the mechanical power transmission by ropes and for further transmission of the signals they are connected by cables (Fig. 2).
 Basis of the TAS development work: Construction and measurement of streamer samples

Towed array developments have their origin in civilian applications in seismology. In the light of the findings gained here, the towed arrays that were constructed back in 1986 – however still with a diameter of 70 mm – can be considered as the ancestors of today’s digital towed arrays. The first operational array (Sonar 90, D = 70 mm) with a length of 185 m was constructed in 1990. Digitalisation of the array was carried out in 1993 on a 400 m long array with a diameter of D = 70 mm. This was followed by a large number of sea trials with surface ships and submarines. The towing trials carried out in a Norwegian fjord by the test agency of the German Bundeswehr (WTD71) with the aid of a winch and a catamaran as the towing unit number among the series of large-scale tests with long arrays. Historically, these activities gave rise to the ACTAS array (Activated Towed Array Sonar) and the DTA 50 (Digital Towed Array, D = 50 mm), which at the same time mark the changeover to an array diameter of D = 50 mm. Furthermore, it was soon found that these large-scale tests are a very resources-intensive way of acquiring data and of assessing the properties of the acoustic system. For this reason, in a test lake near Bremen, besides an existing floating platform, a towing track was set up in which shorter hydrophone sections (length 10 m plus VIM) could be measured.

Fig. 3: Location of the test range and measurement set up

Fig. 3 shows the position of the towing track with a length of 280 m, with which the sections can be measured in situ up to a speed of 11 m/s (22 kn). During these tests, hydrophone signals, acceleration data in the array and e. g. compass information are recorded. Comparisons of the data gained here with measurements carried out in a circulation tank (HYKAT of the HSVA) and the aforementioned large-scale sea trials show that the towing track in the test lake is very suitable for assessing the acoustic properties. Following this, a large number of different test set-ups have been tried and assessed since 1991. Here, investigations of fundamental design parameters such as the diameter of the array (varies between 30 and 90 mm) have been supplemented by detailed work to achieve optimisation of the acoustic structure.
Use of numerical simulation methods

The structure of a towed array shown in Fig. 1 already gives some idea that the acoustic properties of a towed array are decisively influenced by the properties of the materials used. Besides the direct influence of flow noise on the hydrophones (in this context cf Hoffmann et al (2004)), it is above all wave propagation phenomena in the interior of the array that must be named as the source of possible self-noise effects. Of the possible mechanisms:

- Torsion waves,
- Bending waves (transversal waves of the array)
- Shear waves in the case of a gel filling,
- Longitudinal waves ($c_l$) and
- Bulge waves ($c_b$)

above all the two last-named are of importance.

Fig. 4: Mechanisms of wave propagation in a TAS

These are stimulated through longitudinal variations in tensile strength and through pressure fluctuations on the surface. Fig. 4 shows a schematic diagram of the mechanisms. On the basis of an in-house developed FEM code with fluid structure interaction, it is possible for these phenomena to be investigated in the time domain. Here an explicit time integration is used (cf Herrmann et al (1983)).

Fig. 5: FEM discretisation for fundamental of different investigations the TAS (colour coding for values)

Fig. 6: Presentation of the propagation waves in the hose of mechanical stress

Fig. 5 shows an FEM model of a streamer with which these fundamental phenomena were verified. Special objectives of the investigation are here the hardness of the hose materials and the filling of the streamer; in this context, a gel filling is investigated in comparison with an oil filling with a view to the future development of a thinline streamer. Besides the visualisation of the wave propagation phenomena (Fig. 6), Table 1 shows quantitative comparisons between analytical wave velocities, measured values for two different lengths of the test section and the results achieved with the FEM model.
Table 1: Comparison of the velocity of propagation of different wave types

<table>
<thead>
<tr>
<th>hose material</th>
<th>length m</th>
<th>filling material</th>
<th>velocity m/s</th>
<th>measurement</th>
<th>FEM-model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shore 75A</td>
<td>10</td>
<td>oil</td>
<td>102</td>
<td>107</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>oil</td>
<td>102</td>
<td>113</td>
<td>102</td>
</tr>
</tbody>
</table>

It is important to point out that determining the material parameters is of great importance for the accuracy of the numerical simulation. The strength of the numerical simulation method lies in the possibility of also analysing complex structures such as for example the interactions between different components with the aid of detailed models.

**Handling aspects**

During the deployment of a towed array, special attention must be paid to handling aspects. For this purpose, on the basis of the finite elements method a movement model is being developed with which the behaviour of the array can be analysed not only in operational use but also during retrieval and launching (Fig. 7). To this end the structure model of the TA can be coupled to the flow field data in the wake of a submarine that were calculated with a RANSE solver (cf Hoffmann et al (2004)). Using this knowledge of the hydrodynamic behaviour, it is possible to optimise the design of the tail rope that is used for the noiseless launching of the array. The result has been patented and is integrated into the design of the winch (Fig. 8).

![Fig. 7: Results of the movement simulation of the TAS](image)

![Fig. 8: TAS-WHS as a component during the factory trial and integrated into the design of the submarine](image)
Production of the towed array

Based on the experience of the last 15 years, production facilities have been set up with which the complex mechanism of the skeleton including the hydrophones and the digital receiving electronics can be integrated into a towed array system (Fig. 9).

Fig. 9: Production facilities for a TAS

SONAR PERFORMANCE OF A TAS-SYSTEM

System Prediction tool SPIRIT®

To get a reliable and quick overview of the detection of sonar sensors and counter-detection ranges of the actual situation ATLAS developed a new tactical decision support tool SPIRIT® (Sonar Performance Information Range and Integration Tool). SPIRIT® allows the command team to get the best performance during target detection and counter-detection under changing environmental conditions, especially littoral waters.

To allow automatic calculations all relevant sensors are interfaced. The main interfaces are the environment and navigation interface, the array interface with hydrophone data and target data from the tactical server. The environment telegram supplies actual temperature, salinity and sound velocity from the actual probes and the navigation data (Schneider. D et al (2004)). In former times there were fixed tables with frequency and speed dependent average own noise and a sea state input of the sonar operator. Now the level of 96 staves of the arrays is measured by the array interface simultaneously. The tactical server supplies TMA results like bearing, course, range and speed of different targets.

Thus the result of the sonar performance prediction is now based on the actual ambient noise, the self noise, the measured sound velocity profile and the targets data of the TMA. Fixed values like array, signal processing and sea area data are stored in a database.
Performance prediction of the towed array system

The towed array sonar is used for sound evaluation in the very low frequency band. Due to the good propagation conditions for low frequency noise in water, one essential advantage is the long-range detection of targets. Furthermore, most of the specific targets signatures will be found in the lower frequency band. Thus, it is ideal for classification of targets on the basis of evaluated LOFAR data.

Fig. 10 provides the gain of the developed towed array towards the ATLAS flank array. This gain summarises the extended array length and the suppression of the self noise of the submarine and the flow noise at a speed of 6 kt s. The frequency dependent gain of the towed array is a function of the ambient (in this example with Seastate 1 and 3) and the own noise.

![Gain of towed array towards flank array](image)

**Fig. 10: Gain of Towed Array in comparison to Flank Array**

The next two figures (Fig. 11, Fig. 12) provide the performance results of the flank array in comparison to the towed array in the sea area of Crete. In the upper display of each figure a raytracing and in the lower display the probability of detection with LOFAR processing against a silent submarine is provided. Red colour indicates low probability and green colour a high probability of detection. For the calculation a line level of 3 dB above broad-band level at a frequency of 300 Hz is assumed.

The significant range difference between flank and towed array systems results in the above discussed gain of directivity index and own noise level. The detection range of the flank array is in the range of a few hundred meters. In contrast to these the towed array has LOFAR detection ranges of up to 10 kyd against the same target.

For a quick overview of the actual detection ranges (vertical view, Fig. 12) the sonar operator has the possibility to switch on the ‘Bird View’ in the tactical situation display (Fig. 13). To get a direct visualisation of the possible ranges the results of the detection probability in all directions are implemented as a layer (similar to the radar results) in the tactical situation display in own depth. Fig. 13 provides the detection result for a towed array system in a sea area north of Crete for the same parameter as in Fig. 12. Green colour indicates a high detection probability above 75%, the blue colour are stepped light (above 50%) to dark blue (below 25%).
Fig. 11: Probability of detection with FAS LOFAR at 300 Hz towards a low noise target

Fig. 12: Probability of detection with TAS LOFAR at 300 Hz towards a low noise target
The course of the submarine is in north direction, so the ranges for a towed array system towards the quiet target has maximum detection at broadside (green and light blue).

Fig. 13: Probability of detection with TAS LOFAR in the tactical situation display

CONCLUSION

After the successful development of the flank array system for conventional submarines in the late 80th a fully developed towed array system (TAS) is now available. The present paper describes the basis of the TAS, the system components, the construction and measurement of streamer samples. By reduction of the diameter to 50mm it is possible to integrate a winch system into the submarines aft section. To reduce increasing flow noise and to optimise the flow field in the wake of a submarine numerical simulations with structure model of the streamer were made.

The design of present towed arrays can be resumed by two acoustical parameters: a high directivity index and a low self noise level in the low frequency range. With the sonar system prediction tool SPIRIT® it was shown, that even very low noise targets can be detected up to 10 kyd with a LOFAR processing.

REFERENCES

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