DEVELOPMENT OF DREDGE EQUIPMENT IS NO LONGER DRIVEN BY ECONOMY ONLY

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ABSTRACT

Of the “Jumbo” hopper dredge class, with hopper volumes larger than 15,000 m³ (20,000 cu yd), have since the PEARL RIVER of 1994 about 20 models been delivered. These dredges created a new market, specifically reclamation work. These dredges took care that the world’s hopper volume capacity increased with more than 70%. The significant reduction in price per cubic meter/yard dredged material justified such investments. New large self-propelled cutter suction dredges with 24,000-28,000 kW (33,000–38,000 hp installed), of which up to 6000 kW on the cutter, also continue to be built.

Economic evaluations, comparing for instance the cost of blasting in hard basalt and granite type materials versus the production and wear of a cutter, help to determine the present size and justify the investment for such dredges.

But is it only: “larger and more”? Or are other factors also influencing the designs?

The social climate has caused to initiate substantial R&D efforts in the areas sustainability, safety and ergonomics. This paper specifically addresses some recent developments in such other areas:

- The IHC developed “DoDo program”, a dynamic computer simulation of floating bodies interacting with the seabed, allowing to simulate and evaluate the forces encountered on dredging equipment in specific sea conditions. The DoDo software continues to be developed for the hopper dredgers and other floating constructions;
- It lead already to the development such as the IHC Spud Guard, building in flexibility into the anchoring spud;
- The efforts to have larger hopper dredges create less emissions and turbidity per cubic yard dredged; emissions here to be taken in the broadest sense, not only for exhaust gasses such the IMO Tier 2 rule taking effect in 2011, but also issues such as noise reduction.

This paper intends to document that not all developments can be directed at lowering the cost per cubic yard dredged, but that sustainability, including elements as safety and environment also pressure Research and Development efforts and responses are being created.

Keywords: Sustainability, DoDo simulation software, spud guard, propeller improvement, alternative energy.

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DODO SIMULATION SOFTWARE

Wind and swell subject dredging vessels to dynamic forces, which can reach dramatic peaks. Especially when working in open seas, the actual forces can exceed the assumed design parameters. These forces can be magnified by the dynamic forces caused by the dredging process itself, including the constantly varying weight of the slurry that is being pumped. These conditions can have a major effect on the operations of dredging equipment and are an important determinant of the uptime and the operational window of dredging equipment. Operable hours impact immediately the operating cost of both cutter suction dredgers and trailing suction hopper dredgers. In the future the relevance of operability are foreseen to only increase, as dredging operations will more and more take place at larger depths, further offshore and be executed in more desolate areas.

A reliable understanding of dynamic forces to be encountered in a specific job can mean the difference between getting a job or not, between reasonable return on investment or loss, and between damage and injuries or safe operations. These considerations lead to the conclusion that more knowledge had to be gathered about the actual dynamic forces exerted on vessels, equipment and components. When IHC Merwede drew this conclusion, a substantial effort in manpower and cost was committed to investigate the impact of waves on dredging equipment and how to design dredging equipment in a way that the effects of dynamic forces can be minimized and how the operational window of dredging equipment can be maximised.

The company started therefore a few years ago the Research and Development project 'DODO' (which stands for 'Dynamic Operation in Dredging & Offshore') in order to gain more insight in these issues. The aim of this project is the development of a time domain simulation package in which the dynamic behaviour of vessels and dredging equipment operating in swell conditions and interacting with the sea floor can be modelled and simulated.

The dynamics of dredgers are complicated due to the high number of complex external forces acting on the equipment. These forces include for example wave, current, cutting and cable forces. In order to model these forces three different disciplines had to be combined:

- ship hydrodynamics
- multi body dynamics
- soil mechanics

These parameters were eventually successfully combined into one computer model. It created a unique simulation software package. Within IHC it is considered that this program might be the first time that all these parameters, derived from different scientific disciplines, are combined in one simulation environment in such a way that testing approaches measurements in realistic circumstances.

The basis of the combined simulation model is a hydrodynamic equation describing the motion of a floating body. For the hydrodynamic part of the software a simulation package made by the Dutch Maritime Research Institute MARIN has been included. That aNySIM package can simulate the coupled motion behaviour of multiple floating bodies including effects such as mooring systems and hydrodynamic interactions. The external forces exerted on a floating body or bodies are generated with the remaining two disciplines: multi body dynamics and soil mechanics. The multi body dynamics part of the DODO simulation package consists of an IHC made program in Matlab. In this program, the dynamic equations of motion of an interconnected set of rigid bodies are defined. Multiple bodies can be modelled and interconnected using different types of hinges and constraints. In this part of the program the motion of rigid bodies such as suction tubes, spud carriages, cranes, etc. is simulated and the forces acting on and between bodies can be studied. Finally, the soil mechanics part of the DODO simulation package uses soil cutting models for cutters and drag-heads developed by IHC Merwede. In this module also a certain ground profile can be modelled and the movement of a cutting tool (e.g. cutter or drag-head ) through the ground can be visualized.(see Figure 1)
The need for calibration and validation was recognized – these necessities are always addressed when working with models and simulations. In January 2010 an extensive validation campaign was executed with the largest cutter suction dredger of the standard Beaver series. An IHC Beaver 6518C was fitted out a prototype of a new standard flexible spud carriage and installed with lots of force, acceleration and position sensors. Also a wave buoy was deployed in order to relate the measured movements to the actual wave characteristics. A ten days measurement and testing program was performed, providing a unique set of validation data. These validation data proved to be essential to evaluate the validity of the DODO simulation package and to improve its prediction capabilities.

Later this year an extensive measurement campaign is planned with a trailing suction hopper dredge.

There are countless applications for the DODO simulation package. IHC Merwede has already conducted several research projects including:

- simulation of the newly build 26,000 kW self propelled cutter suction dredger Athena, equipped with a new type of flexible spud carriage system and a flexible supported deckhouse (see Figure 2)
- simulation of a suspended drag-arm of a hopper dredge, swinging above the waterline (see Figure 3)
- simulation of a Beaver 6518C cutter dredging with a flexible spud carriage system (see Figure 4)
- simulation of a tin mining vessel operating in swell
An additional requirement for the DODO software being developed is that the software code has to have a generic setup. This way not only cutter suction dredges or trailing suction hopper dredges can be modelled, but in the future also other kind of vessels can be included and simulated, for example pipe laying vessels and crane vessels. The overall aim of the development is the creation of a generic dynamic simulation package for all of IHC Merwede’s products while operating in sea conditions.

It is proving that by this generic Research and Development approach, the company created a design, prediction and optimisation tool by which multiple type of vessels and equipment coupled to the sea floor can be modelled in a flexible, fast and easy way. This tool allows the engineers to improve the design and the performance of its dredging equipment and offshore vessels in areas for which in the past more assumptions than actual data were applied. By predicting and improving the operational behaviour of these vessels more accurately, IHC Merwede can realise a safer work environment, cost savings and improved return on investment for its clients.
THE “SPUD GUARD”, A FIRST STANDARD PRODUCT DEVELOPMENT SUPPORTED BY DODO

When the very large Cutter Suction Dredges JFJ DE NUL (27,240 kW installed, with 7600 kW on the cutter) and the ‘ARTIGNAN were designed, special design efforts were given to the forces created and experienced on the spuds and their holding mechanisms. The URSA had applied earlier a spud carrier on wires. However, the weights of the suspended equipments on these dredges (roughly 1500 metric ton ladders and 200+ metric ton for each spud) was well beyond the weights and forces of previously applied tools. For calm sea conditions spud peak force absorbing systems for calm waters were developed, one with wires the other using hydraulic cylinders for tensioning.

DODO allowed a better insight in those forces and facilitated the development of the “Spud Guard” for the standard cutter suction dredges. A spud carrier fitted to a standard IHC Beaver 6518 cutter suction dredger was developed with hydraulic buffer cylinders. That set-up allows to increase its flexibility when facing more extreme weather (wind and wave) conditions.

The hydraulic buffer cylinders are connected to nitrogen pressure vessels. The pressure can be pre-set to move the cylinders in or out at pre-defined forces acting on the spud connected to the sea floor. This allows the cutter suction dredge to move along with the waves within a certain spectrum. In case a too large force is encountered the step cylinder adjusts its position to prevent the spud from bending or even breaking. The “flexible spud carrier” is recommended to reduce the potential risk of damage caused by more extreme sea conditions. In addition to this built in safety, the impact of the sea state on the spud load can be made visible. This allows also the operator himself to be aware of the circumstances he is dredging and allows him to make himself a judgment whether to cease or to continue dredging. As most dredge operators select the “better safe than sorry” principle, the information provided is expected to contribute to an increased availability of the equipment.

An IHC Beaver® 6518 C with an integrated flexible spud carrier will was thoroughly tested during a 10 day testing program.

Figure 5. The Beaver 6518C® with step spud-carrier pontoon being tested in the Haringvliet estuary
In a large river, Haringvliet, sealed off from the North Sea, static test were executed. Subsequently, the dredge was extensively tested in the North Sea during January 2010. That became one of the most intensive testing programs IHC Merwede ever executed on a standard dredge. The dredge was turned in different directions to test wind and current from different directions. The dredge was tested without ladder and spuds down, with ladder down at different dredging depths and spuds up and down. Many other variables were tested.

Figure 6. North Sea tests in January mean less favourable weather conditions- as intended!

A major part of the testing was done to validate the DODO program However, also the “Spud Guard” endured the different tests- the measurements documented the added equipment was able to protect the spud, with which the cutter was anchored to the sea floor, within the set limits against the force of the waves and currents the cutter dredge experienced.
The results of the tests and evaluation thereof, proved the Spud Guard is a true add-on for safety. Following those conclusions, the product was made commercially available.

CUTTING OUT THE DOWNSIDE OF CONTINUOUS IMPROVEMENT OF PROPULSION PERFORMANCE

The R&D for trailing suction hopper dredges, the last two decades have gained fame as a period of extensive research and application of hull improvement of that type of dredge. The never ending need for increased deadweight, achieved at the same, but if possible even at higher, ship speed ended up at a so called block coefficient (Block coefficient “Cb” = moulded displacement / (LxBxT) ) of almost 0.9 at a Froude number (Relative speed \( \text{Fn} = \text{vessel speed} / \sqrt{(L \times g)} \)) up to 0.23 nowadays (please note, a hopper dredge has the fullness of a tanker and a relative speed of a passenger vessel).

From the above scatter diagrams in Figure 8, it can be concluded that the transport efficiency, the product of deadweight and speed, has increased significantly thanks to these developments.
Taking into account the ratio of the main dimensions of a hopper dredge, one may conclude that these Figures show a rather extreme tendency. The Length/Breadth ratio of a hopper dredge has decreased to a factor 4.0 and it will be clear that for such a ratio the ship’s hull gives little room for further improvement. Nevertheless, extensive research was leading recently to a surprising improvement of more than 5% propulsion power. Over a period of 20 years a total gain in propulsion performance has been achieved of 25%, see Figure 9. Where will be the end?

![Figure 9. Result of 20 years of hull improvement](image)

Optimization tools as CFD (Computational Fluid Dynamics) have proven to be very helpful tools to improve the hull. However, one should take care of a correct application of the tool. Especially for hopper dredges with their characteristic complicated stern operating in extreme circumstances, several pitfalls present itself during a design. Therefore, model testing is still an applied method of validation to verify the speed/power relation of the dredge. Unfortunately, such a procedure does not guarantee an outcome as expected. The problem is that CFD will not have a vessel’s speed as an outcome and on the other hand the model test suffers of scale effects, especially in shallow water. Further research and development is required to improve the accuracy of CFD and to get a reliable extrapolation procedure for shallow water. Both are essential to enable specific hull design for trailing suction hopper dredges.

At this moment IHC Merwede can develop a proper design, realizing the deficiencies of the tools. Full scale measurements will help the designer to evaluate the outcome of CFD and model tests. This procedure has been used during the last years and lead to hopper dredges with excellent hull characteristics. However, this does not mean that all technical problems have been solved. We address here one specific “detail”: the propeller.

The design of a propeller blade of a hopper dredge is already rather complicated under normal circumstances, due to the wide range of different conditions. These conditions have all the same importance within the operational profile of the dredge, so the designer is obliged to find a good balance in cavitation performance between all. Just that is making the blade design difficult. For example, sailing in empty condition full speed ahead with low hydrostatic pressure and large pitch of the Controllable Pitch Propeller differs widely from dredging at very low speed with a high thrust demand at low pitch. The blade curvature must be such that in both conditions the cavitation behavior is minimized to an acceptable level. On the other hand, sailing in deep or shallow water results in a different wake field. On top of that, the wake field in empty condition with large trim has a more pronounced character than the wake field in loaded condition on deep draft at even keel. see Figure 10.
One thing is clear: cavitation cannot be avoided in so many conditions and it is the art to find a good compromise. However, due to the increased fullness of the hull, the quality of the wake field has changed. The character makes it even more difficult to design a dedicated propeller blade.

Although from cavitation point of view a compromise could be found for the blade design, the propeller noise appeared at the end to be not satisfactory. Of course, the propeller designer did his utmost to keep the propeller efficiency as high as possible during the blade design process. It is well known that a large blade area at the tip in the nozzle results in a higher thrust. The down side of this efficiency driven change is that the propeller load moves towards the tip. Although it increases the nozzle thrust, unfortunately it also makes the tip vortex stronger. This results in unappreciated noise levels, as we experienced. To get rid of the higher noise levels, some thrust had to be exchanged for comfort. To minimize the loss in efficiency, the most beneficial edged blade contour from thrust point of view has been changed in a well rounded contour, see Figure 11.

As can be observed in Figure 11 the change is only small. The loss in thrust is expected to be 1% to 1.5%, but the decrease of noise level was remarkable. For a modern recently built hopper dredge the propeller blades have been changed like Figure 11 during the dry docking of the vessel. After return to operation extensive noise measurements have been done in all relevant conditions. At all conditions the noise level in the silent area of the engine room above the propellers appeared to be lower than with the original edged blade tip. Especially the loaded free sailing condition shows a remarkable decrease of the noise level and could be nicely compared with that of the sea trials with the original blade tips, see Figure 12.
Continuous improvement in one direction (economics) can have a downside for other relevant aspects. To satisfy the end user it can happen that loss of efficiency must be accepted to overcome these downsides. For hopper dredges a small step backwards was needed in the endless run of improvement of propulsion performance to sweeten the live of the crew.

**ALTERNATIVE ENERGY**

Sustainable product development in dredging is recognized in IHC to contain the following elements of the following major topics:

- Energy and emissions
- Spill and turbidity
- Materials use
- Air and Underwater noise

Dredgers consume much energy and therefore increasing the efficiency and decreasing harmful emissions results is an great improvement of the sustainability performance of dredging vessels.

It is now commonly accepted that we are at the moment or even beyond the “peak oil” point, meaning oil will become increasingly scarce and expensive in the years to come.

One of the technologic solutions currently available is shifting from diesel to gas as fuel. This allows both high energy efficiency (50%) and reduced NOx (-99%), SOx (-100%) and CO₂ (-25%) emissions.

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**Figure 12. Reduction of noise due to adjusted propeller blades**
The IMO emission legislation sets worldwide limits to the emissions of SOx and NOx. Further, recent European Union legislation sets very low SOx emission limits for the EU Port areas. In the near future, CO₂ legislation is also expected (Note: CO₂ emission legislation is being discussed at IMO at the moment This means that new built vessels will be evaluated according to their CO₂ emission index, obtaining possibly some kind of `label’ and paying taxes according to emission levels. A minimum emission level is likely to be established.). Figures 13 and 14 show the emission limits according to the NOx and SOx legislations. For vessels operating in inland waters (such as cutters), even more strict emission legislation applies, and diesel engines used in these vessels must comply with the regulations (see European Directive 2004/26/EC and CCNR in report DZ05). (Vessels not entering the ECA’s of European Ports do not have this restriction. However, it is expected that many countries will apply at IMO to obtain ECA status, possibly leading to a stringent worldwide NOx and SOx restriction). Figure 16 presents the Sulfur content of several fuels.
The following options arise for the power supply of vessels after 2015 to comply with SOx limits:
- Post-combustion cleaning of the exhaust gases when using high content S fuels using a Scrubber
- Changing to Low Sulfur (LS) fuels
- Shift fuel: gas (gas engines, gas turbine)
- Shift of fuel and power supply technology: fuel cells

The following options arise therefore to comply with NOx limits:
- Engine modifications make it possible to comply with Tier II, at cost of engine efficiency (note: Estimated efficiency loss of 10% due to lower combustion temperature, in order to reduce NOx formation by 20%)
- Post-combustion cleaning of the exhaust gases using a SCR (Selective Catalytic Reduction)
- Shift fuel: gas (methylene)
- Shift of fuel and power supply technology: fuel cells with hydrogen, methane or methanol

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Denomination</th>
<th>Sulphur content (%) m/m</th>
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<tbody>
<tr>
<td>HFO</td>
<td>Heavy Fuel Oil</td>
<td>&gt; 1.50</td>
</tr>
<tr>
<td>LSHFO</td>
<td>Low Sulphur Heavy Fuel Oil</td>
<td>&lt; 1.50</td>
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<td>Light / Distillate Fuel Oil</td>
<td>0.21 - 2.00</td>
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<td>Low Sulphur Light / Distillate Fuel Oil</td>
<td>0.01 – 0.20</td>
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<td>H2</td>
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Figure 15. NOx limits IMO legislation

Figure 16. Sulphur content of various fuels
GAS ENGINES

There are mainly two types of gas engines

- Gas engine with Diesel pilot
- Lean burn gas engines

Gas engines with diesel pilot use an amount of diesel to start combustion and then inject gas. They have been recently developed into ‘dual-fuel’ engines, that can use a variable amount of gas en diesel. The possibility to use two fuels offers high flexibility, but possible weaknesses are the efficiency and response time to load variations. The complexity of the system also increases due to the presence of two fuel supply systems.

Lean burn gas engines work only with gas, and are therefore less flexible. They have however a high efficiency and faster response to load change (claimed by manufacturers). These engines offer the highest emission reduction as well, because of burning only gas.

It was concluded that both advantages and disadvantages needed to be investigated in more detail to determine the possible applicability of such an engine onboard a CSD.

![Figure 17. Fuel cell principle](image)

The Encyclopedia Britannica defines a fuel cell to be any of a class of devices that convert the chemical energy of a fuel directly into electricity by electrochemical reactions. In that it looks much like a battery, however the components used result in a much longer life.

In the fuel cell considered Hydrogen in a reaction with oxygen is converted in electricity. Electric power can be produced when a power demand. The pursuit of useable fuel cells was initiated again half a century ago for the space industry.

**Beaver 40® Test**

When its new design Beaver 40 dredge was ready to be tested, IHC’s R&D lab MTI Holland in cooperation with the manufacturer of the dredge, IHC Beaver Dredgers, extended the test to include a fuel cell generator; a test to observe if a fuel cell could provide all electric power to the dredge, in stead of a using a stand-alone harbor set.
Hydrogen requires strict safety measures, as it is flammable (As we know from the Hindenburg 75 years ago!) Rules and regulations for use of fuel cells are being developed by leading classification societies and continue to be upgraded. That was also one of the reasons to rent an approved, commercially available fuel cell generator of about 4 kW (5 kVA), complete with 200 bar (3000 psi) Hydrogen bundles was rented. The storage bundles with Hydrogen represented still a significant volume, and it is something that will need to be reduced in the future.
Figure 20. The test and measurement unit with the Beaver 40 being tested in the “Haringvliet” estuary.

Figure 21. The test program did not test the fuel cell alone, also the new Lancelot cutter was tested.
The Beaver 40 is a new standard cutter dredge model itself, while new components, such as the new Lancelot cutter were also tested.

**Results**
The fuel cell aggregate performed well. During the full test program of 120 hours the Beaver 40 the aggregate provided all electric power for the dredge. The unit proved to be able to handle the typical dredge circumstances, such as vibrations, frost, humidity and continuous use.

The results were beyond expectation. Based on the present results, it seems not unreasonable to expect that the ROI, Return On Investments, in such an alternative energy source could be based on a couple of years. Plans for further investigations have been submitted and will be performed.

**CONCLUSION**
There are other factors than lowest price per cubic yard that determine right now Research and Development plans of dredge equipment. The pressure of the world surrounding us requires that issues such as “sustainability” are no longer quoted alone in Vision and Mission statements, but are also truly investigated. This paper illustrated that investigating actual rather than assumed forces at sea with the newly developed DODO program, the investigation of noise by propellers and the application of fuel cells not only show commitment to take “sustainability” serious, but the reader may also have noticed that each of these research efforts, initiated from another perspective, may actually also contribute to a more economic process.

**REFERENCES**

**CITATION**