MODULAR APPROACH IN CUTTER SUCTION DREDGE DESIGN

J.M. van Helden[1]

ABSTRACT

New developments in the market, mainly in China, gave us new challenges. The standard dredging equipment available was not suitable to face these challenges and the alternative for a custom-built design was considered expensive and time consuming. Therefore a new concept has been devised in which the design of the dredge is broken down into smaller units and systems, like cutter head unit, ladder pump unit, booster pump unit and spud carriage unit. In this concept it is possible to combine these standardized modules into a new design which would meet the specific requirements of the client. In this paper we give examples of how this concept has been applied in new designs and what the advantages and disadvantages with regard to design optimization, cost, delivery time, dredge construction, dredge operation etc are. Furthermore we look at how these dredges are constructed and how they are performing in normal operation since their commissioning.

Keywords: Cutter suction dredge, dredge design, efficiency

INTRODUCTION

China's economic growth during the last decades impresses the world. In order to sustain this growth, investments in large infrastructure and development projects have been initiated and dredging is in the forefront of many of these projects. The majority of the projects are in and around the estuaries of the main rivers in China and along the coastline close to economic centers including Shanghai, Tianjin, Guangzhou and Hong Kong. The dredging contractors in China took this challenge but discovered that their present fleet of inland cutter suction dredges was not capable of reaching the required dredging depth, nor the required production or meeting the required constraints in these remote locations. IHC was approached by dredging contractors in China to design and deliver dredging equipment that would meet the requirements.

In 2003 IHC was awarded a contract for the design of a custom built 8000kW Cutter Suction Dredge. The dredge was to be built with a local Chinese yard, however IHC had to deliver the vital components. This order became a custom design. To simplify the assembly process and reduce the construction time, the different modules were projected on deck and not inside the pontoon. As an example the second inboard dredge pump is placed on a dismountable foundation to allow easy installation. Furthermore this also allows the flexibility of easy relocation of this pump to other dredging sites. This was the first design concept targeting this ease of production, however without sacrificing functionality.

In the period after the award of this first contract it was decided to explore the modular concept further. This resulted in the design of a smaller dredge based on both the IHC standard Beaver cutter suction dredges and the above mentioned custom built cutter suction dredge. Till the end of 2006, this led to contracts for in total twelve (12) cutter suction dredges derived from this design to be constructed in co-operation with local yards in China.

In this paper we will elaborate on various aspects of this modular design approach like design optimization, costs, delivery time and dredge construction. We also have a look at how these dredges are performing since their commissioning.

POSITIONING OF THE NEW MODULAR DESIGN APPROACH

When IHC was approached to supply this Cutter Suction Dredge design, the Dutch design office first analyzed the standard equipment designs and recently built custom-built dredges to evaluate whether this equipment would suit the requirements. These requirements included, among others, a cutter power of 750 and 1000 kW respectively and

[1] Project Manager, IHC HOLLAND Engineering & Renovation BV, 24 Molenstraat, 2961 AL Kinderdijk, The Netherlands, T: 0031-78-6910235, F: 0031-78-6910231, Email: j.m.vanhelden@ihcer.com.

a dredging depth of 25m. Construction aspects were also an important parameter, as this type of dredge would be built in co-operation with local yards.

In IHC's analysis the top sizes of the range of the standard IHC cutter suction dredges were evaluated, as well as a selection of custom-built cutter suction dredges that came closest to the specified requirements. The analysis resulted in a selection of two modular designs, which were labeled 7025MP and 7525MP. In this designation, the first two figures refer to the suction line diameter in cm and the third and fourth figure refer to the dredging depth in meters. The letters MP stand for Mono Pontoon, i.e. not demountable. These two dredge designs finally led to the modular approach for the design of cutter suction dredges for the Chinese market.

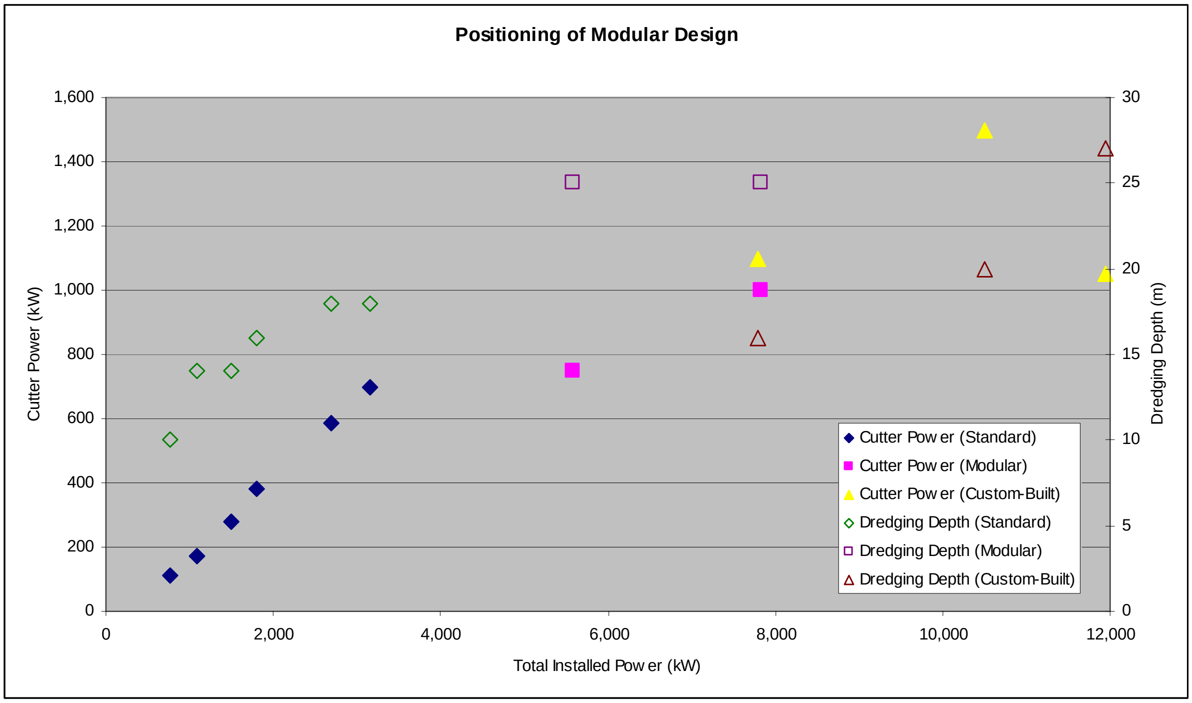


Figure 1. Overview of analyzed cutter suction dredges.

In Figure 1 both cutter power and dredging depth are plotted against the total installed power for the various cutter suction dredges used in our analysis as well as for the resulting two modular dredges (7025MP and 7525MP). The standard IHC cutter suction dredges can be found on the left side of the graph with the custom built dredges on the right hand side. The required dredging depths for the modular designs are relatively large and exceed dredging depths of the standard range of cutter suction dredges by far. They even exceed depths of some of the custom built dredges. The required cutter power for the modular designs of 750 and 1000 kW is positioned between the range of standard IHC cutter suction dredges and the range of custom built cutter suction dredges.

The position of these new designs together with the requirement for a short construction time and provisions to allow design variations to suit different customer demands, challenged us to come with a new working process. This resulted in the above mentioned new modular approach.

DESIGN CONCEPTS

Standard versus Custom-Built

In order to get a balanced definition of the Modular design we first have defined main characteristics of both 'Standard' and 'Custom Built' designs. Characteristics for 'Standard' IHC designed Dredges are:

– Suitable for the widest range of dredging jobs possible

– Have a high efficiency in its whole working range
– Have a short delivery time due to the availability of the design and main components (in many cases ‘Standard’ IHC Beaver Dredges can be delivered from stock)
– May be able to take advantage of the fact that spare parts are available on stock
– No competitive edge when competitor get hold of the same equipment
– Proven design and technology
– Lower initial investment cost compared to ‘Custom Built’ dredge of same capacity.

Characteristics for ‘Custom Built’ Dredges are:
– Designed for customer specified dredging jobs
– Have optimum efficiency in the specified working points
– Design is tailored to the specific demands and requirements of the customer
– Longer delivery time due to the fact that the design and approval process will only start after the awarding of a Contract.
– Higher initial investment cost compared to ‘Standard’ dredge of same capacity.
– Higher production compared to ‘Standard’ dredge which is a General Purpose dredge and not optimized for that particular job.

Modular design

In the previous section it is shown that, based on cutter power and dredging depth, the Modular Design is positioned in between the range of Standard Custom-Built dredges. The intention of modular approach cutter suction dredge is to strike a balance between the design of ‘Standard’ and ‘Custom-Built’ dredges by combining the advantages and minimizing the disadvantages.

MODULAR DESIGN APPROACH

Working Process Assumption:

The working process assumption for the modular design approach is that for the functional design it must be possible to break up the cutter dredge in semi-autonomous modules or units. It should be possible to combine them in multiple design configurations, leading to different cutter suction dredge design possibilities, each one with its own characteristics and dredge performance.

Definitions:

Cutter Suction Dredge:	Cutter Suction Dredge, floating working platform for the cutting and hydraulic transporting of soil.
(Main)System:	set of components and/or tools working together as a mechanism or interconnecting network
Subsystem:	a lower order system within a system
Module:	a set of systems or units that can be used to construct a more complex structure.

Break-Down into Main Systems

When we analyze a cutter suction dredge, we can identify production related modules and supporting modules, each one composed of several main systems.

Cutter Dredge Production Related Modules

– Cutting system.
This system comprises the cutter ladder with the cutting unit, the ladder gantry and the ladder hoisting winch with accessories. The cutting unit can be either a cutter unit or a wheel unit. These units are interchangeable.

Figure 2. Business-ends of cutter ladders ready for transport.

- Pumping system.

- The pumping system comprises the dredge pump on the cutter ladder and one or two booster pumps on the pontoon. The engines and other equipment driving these pumps are part of the pumping system. Ladder pump and booster pump for a modular design are of the same type. Allowing interchangeability of impellers and other wear parts.

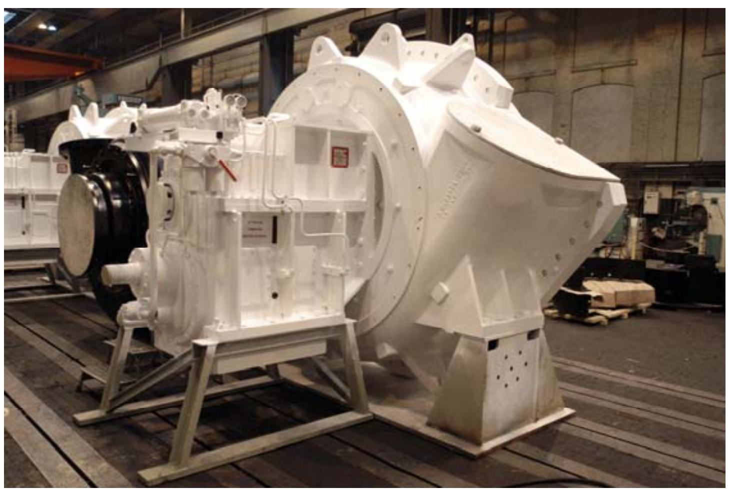


Figure 3. Dredge pump with integrated gearbox-bearing block.

- Spud system.

  The spud system comprises the working and auxiliary spud with all equipment required for the hoisting and lowering of the spud and optional tilting of the spuds. A spud carriage for moving the working spud, including the spud step cylinder is also part of the spud system. The spud carriage can be mounted in a spud carriage well in the pontoon construction of the dredge or in a well in a separate idler pontoon which is than connected to the pontoon structure of the dredge. Spud carriages in idler pontoons are commonly used with the smaller standard cutter suction dredges. Although idler pontoons are also used for large cutter suction dredges in the USA, it is common practice in Europe to incorporate the spud carriage in the hull of the dredge.

Figure 4. Spud carriage and auxiliary spud.

Figure 5. Spud carriage.

– Swing installation.

The swing installation comprises the swing winches and the optional anchorboom installation including its equipment.

Figure 6. Swing winches and ladder winch.

Supporting Modules

– Floating platform (i.e. pontoon)

Dimensions and shape of the pontoon depend on requirements for swing width, required space on board for the necessary equipment and whether or not a spud carriage will be installed. The pontoon is not considered a standard module. Depending on requirements with regard to length and space for the mounting of the various other modules, the design of the pontoon will vary and be custom built. For the modular dredge designs discussed in this paper and considering the size of the dredge we selected a mono hull pontoon. Such a design is not dismountable.

Figure 7. CSD barge module

– Accommodation

Figure 8. Accommodation deckhouse under construction.

– Dredge Operator Cabin

Figure 9. Dredge operator cabin.

Component Selection

After definition of the various modules and categories for the modular designs, the availability of various dredging related modules from both standard IHC cutter suction dredges and Custom Built cutter suction dredges in the target range were evaluated. In total five 'Standard' cutter suction dredges and two 'Custom-Built' cutter suction dredges were reviewed as a typical example in the design range considered. Latter types were the SNP dredge built for South Korea and a dredge built in China in 2003 designated as type 7525MP. The present series of modular dredges delivered and under construction in China has been designated as type 7025MP.

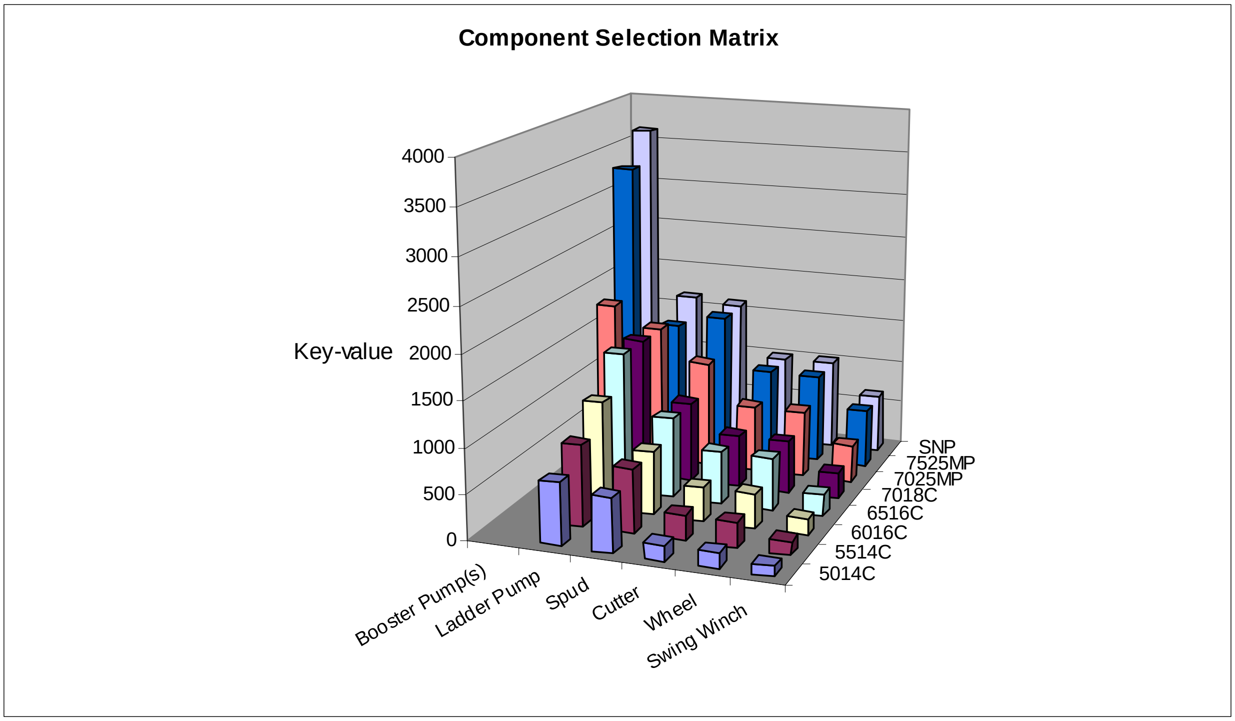


Figure 10: Component selection matrix.

In the graph (figure 10) the following dredge component modules are presented with a signifying key-value for each of the type of dredge it has been originally designed for:

- Swing Winch.
  Representing the swing winch installation with the nominal winch pull (kN) as key-value.
- Wheel.
  Representing the cutting wheel installation with the wheel power (kW) as key-value.
- Cutter.
  Representing the cutter installation with the cutter power (kW) as key-value.
- Spud.
  Representing the spud installation, including spud carriage, with the spud diameter (mm) as key-value.
- Ladder Pump.
  Representing the ladder pump installation with the pump power (kW) as key-value.
- Booster Pump(s).
  Representing the booster pump installation with the total booster pump power (kW) as key-value.

Relation between Systems

The various systems which together make up a functioning dredge have to be balanced well and the relations between systems have to be considered when selecting the components/tools for these systems. The following relations between those systems can be described:

- Pontoon – Swing installation.

  The pontoon should be of sufficient length to enable required design cut width and also allow installation of all equipment. The swing installation is dimensioned by the cutting installation, with cutter or wheel module, and also by the size of the pontoon. Due to the direction of the cutting force the swing pull for a cutter is higher than for a wheel of the same power. When the dredge has to operate in areas with a relatively high current, the part of the swing winch pull required for swinging will become significant and may require the installation of heavier swing winches.

- Swing installation – spud installation.

  During the dredging process the dredge is swinging around its working spud by means of the swing winches which are connected to the swing anchors. The swing winches, the cutting force and the external forces like current and wind will exert a force on the spud which anchors the dredge. There is a direct relation between the force on the spud and swing pull.

- Cutting installation – pump installation – swing installation

  In order to ensure a good overall production it is important to balance design specification of these three installations. First of all the right cutting tool has to be selected for the soil. Secondly in order to be able to use the available cutting force sufficient swing pull should be available as well as sufficient compensation for the reaction force of the cutting tool. Thirdly the pump installation should match the cutting installation. Here the type of soil to be dredged is a determining factor. Depending on the soil either the cutter or the pump will be the limiting factor in the production figures. In the case of free running sand the pump installation will be the limiting factor while in the case of rocky materials the cutter will be the limiting factor.

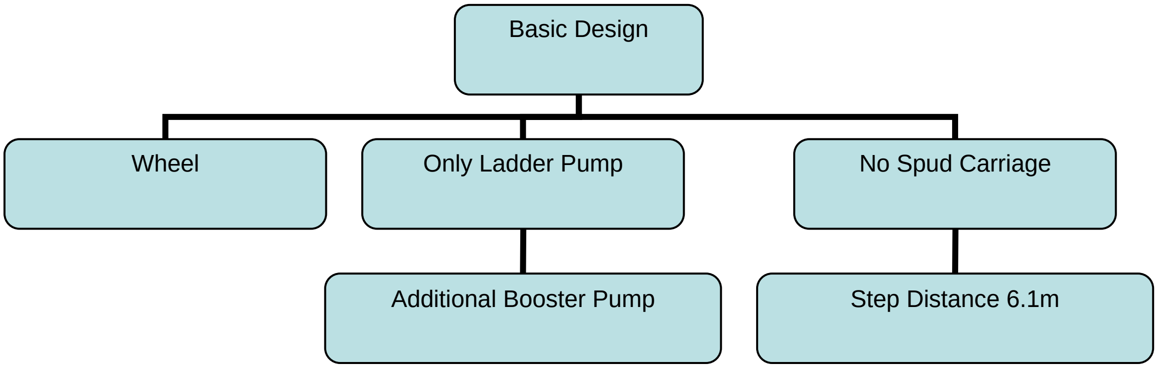
Besides the above, these systems are related to and influence each other. It is also important to note that the design of these systems and selection of equipment for these systems depends on overall design conditions of the dredge. Considering these overall design conditions and the relations between the systems, the variations in realistic options are reduced to a few actual options. Furthermore, it proves that it can be profitable to have one experienced designer to combine all relevant systems in one integrated design and advise on the selection of components.

Example of Design Variations

In this section some examples on the consequences of various design variations are given.

The concept of the 7025MP as starting and reference point is used and has the following main characteristics:

– Cutter power	750	kW
– Ladder Pump Power	1550	kW
– Booster Pump Power	1779	kW
– Spud Diameter	1200	mm
– Spud Step Distance	4.8	m



Cutter or Wheel

The selection of either a cutter unit or a wheel unit mainly depends technically on the type soil to be dredged. The production of a cutter and a wheel unit depends on the material to be dredged. In general a cutter is selected for harder but free flowing materials while a wheel is selected for dredging cohesive soil and controlled high production. Selecting a wrong tool for the job can have big impact on the overall production of the dredge. Based on the soil information supplied by the client IHC can advise on the selection of either a cutter unit or a wheel unit.

Installation of 1, 2 or 3 Pumps

The reference design concept has one pump on the cutter ladder and one pump on the barge. Both pumps are of the same size and have the same impeller dimension. The ladder pump is single walled and the inboard or booster pump is double walled. In the 7525MP type dredge the same dredge pumps are use, but an additional booster pump has been installed. In the graph (Figure 11) the pump output is plotted against the discharge length for one, two or three pumps working in series.

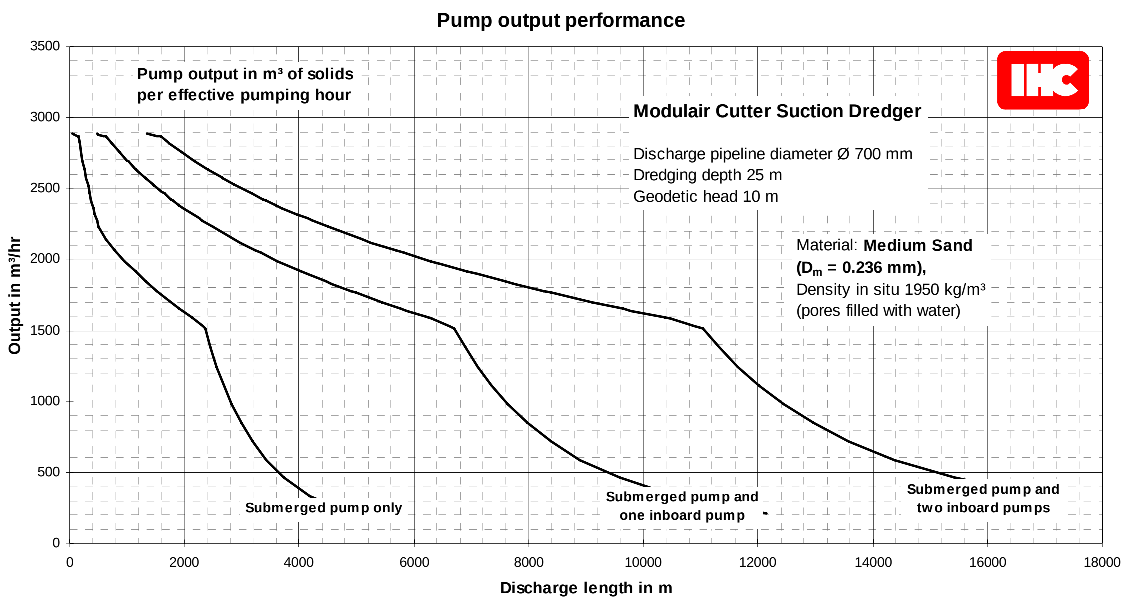


Figure 11. Production graph.

The installation of two booster pumps allows pumping over longer discharge lines or higher production for shorter discharge lengths. Having two booster pumps creates a certain redundancy as one of the booster pumps can be by-passed to continue dredging operations while the other is out of order for maintenance. This is only possible when site conditions determine only a limited drop in production. The installation of two booster pumps has an impact on the space available for other units. Within the reference design concept the second, additional booster pump, can only be installed when space for the accommodation or another unit is sacrificed.

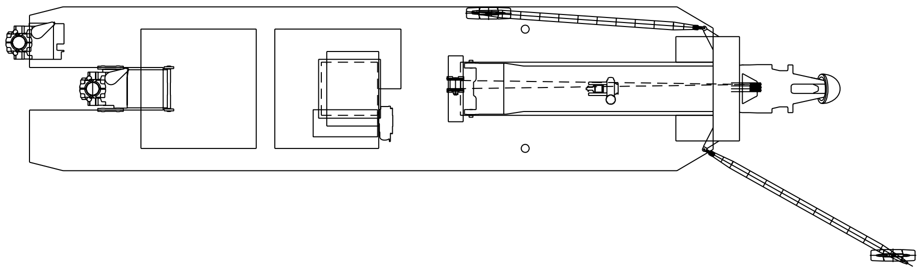


Figure 12: Arrangement with one booster pump.

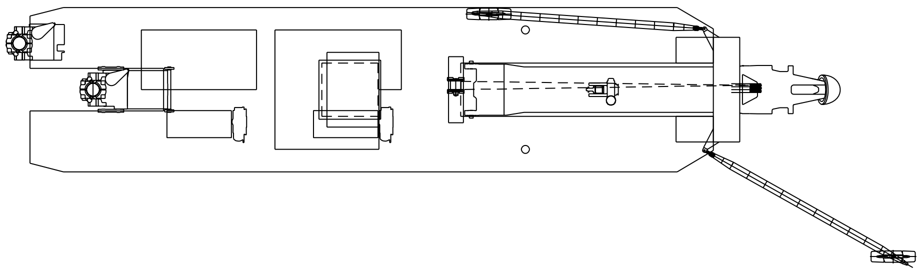


Figure 13: Arrangement with two booster pumps.

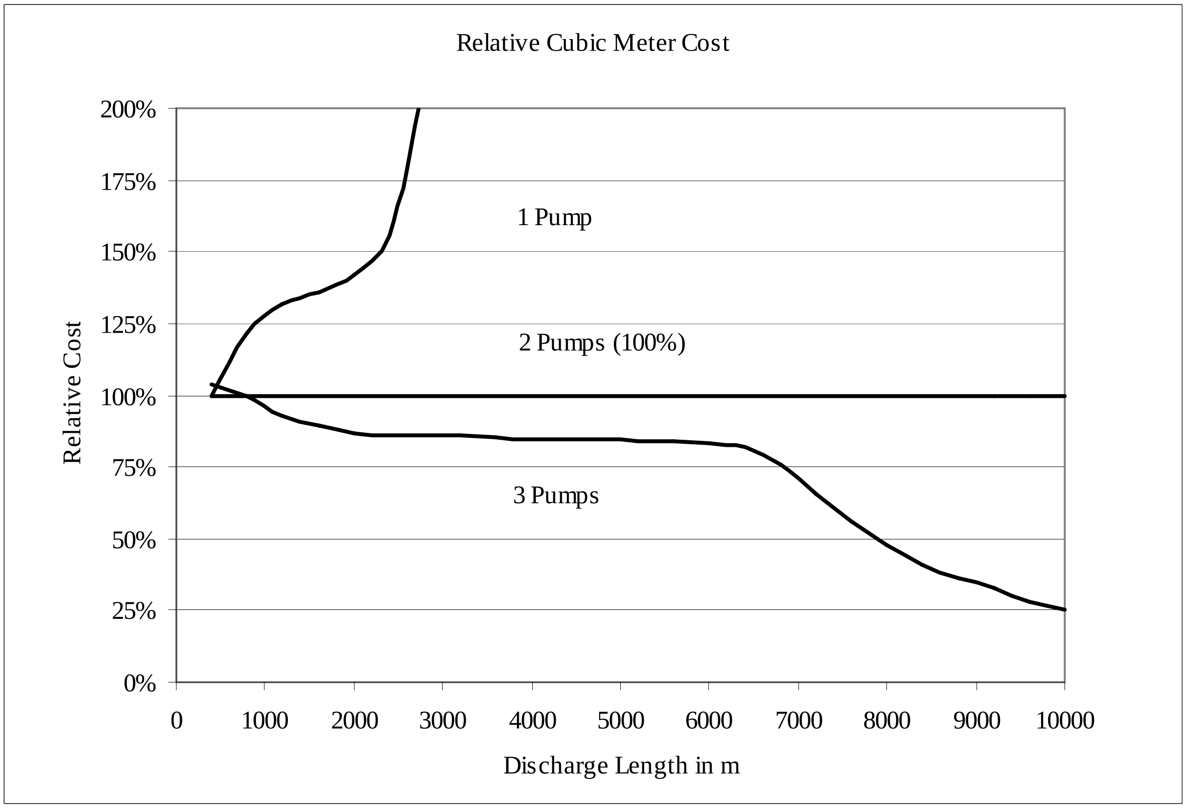


Figure 14: Relative cubic meter cost graph.

The installation of an additional booster pump on board also has an impact on the initial investment costs of the dredge and the production.

The graphs (Figure 14) shows the relative cubic meter costs for 1 and 3 pumps compared to the basic concept with 2 dredge pumps. In the calculation we have considered the variation in the investment costs, i.e. the cost reduction for a concept with only one pump or cost increase for installing one additional booster pump, also considering the variation in production. From this graph it becomes clear that the deletion of the booster pump results in a dramatic relative increase in costs per cubic meter dredge material.

The installation of an additional booster pump results in an increase of relative cost on a short discharge length and a relative cost reduction on larger discharge length with a decrease for long discharge lengths. Economic viability of this additional investment depends on costs per cubic meter and the type of dredging jobs the dredge will be applied.

Spud Installation

In this section the influence of alternatives in the spud installation on the design of the dredge and the cost effectiveness of the design is explored. The reference dredge has a spud installation with a spud carriage integrated in the main hull of the dredge with a step distance of 4.8m. Two options are compared. One option is the omission of the spud carriage from the spud installation and work just with two fixed spuds. The second option is the increase of the working spud step distance.

When the spud carriage is deleted from the design this creates space on the main hull which could be used for the installation of other modules, for example an additional booster pump module or an increased accommodation deckhouse. However, the deletion of a spud carriage can have a considerable impact on the dredge operation and production. When a spud installation with two fixed spuds is applied, the dredge operator is required to hoist and lower the two spuds more frequently which will reduce the effective dredging time of the dredge. The more frequent the spuds will have to be hoisted and lowered also depends on how a dredging job is approached.

A dredge job can be approached theoretically by either dredging layer for layer or cut for cut. In the first one a lot of forward and backward movement of the dredge is required and therefore also a lot of spud handling. In the second approach the dredge is stationary longer and dredges on one spud position till a desired dredging depth has been achieved by dredging in the same spud position at increasing cutting depth. This approach requires less spud handling activities than the first one. In reality a combination of the two described approaches is used pending on the soil and job requirements.

When the spud carriage step distance is increased from 4.8m to 6.1m this will increase the efficiency as the amount of spud handling is further reduced. The increase of the step distance will increase the length of the spud carriage well and within the same main dimensions reduce the space in and on the main hull for other equipment. Furthermore, increasing the step distance can not be done unlimited. The spud step cylinder is subjected to a large compression force resulting from spud reaction force. Above a certain length the buckling of this cylinder will be a determining factor and the cylinder will become too large in relation to the connecting equipment.

In order to visualize the above we have calculated the efficiency of the various options relative to the reference design concept. In the comparison it has been assumed that the anchors do not require to be repositioned and no time for swing anchor repositioning has been included. Here Production Efficiency is defined as follows:

$$\text{Production Efficiency } (\eta) = \text{Dredging Time / Cycle Time}$$

In this the Cycle Time is the sum of the following process intervals:

- Dredging time during swing [s]
- Time for spud hoisting and lowering [s]
- Time for spud carriage movement [s]
- Time for cutter ladder hoisting and lowering [s]

The Cycle Time is calculated differently depending on whether the dredging is done layer for layer or cut for cut. Here we also have to consider that the increase of the working spud step distance or the deletion of the spud carriage have an influence on the initial investment (capital) costs. This influences the exploitation costs. Calculating the exploitation costs requires to deal with many parameters like construction, labor and fuel cost which can vary considerably.

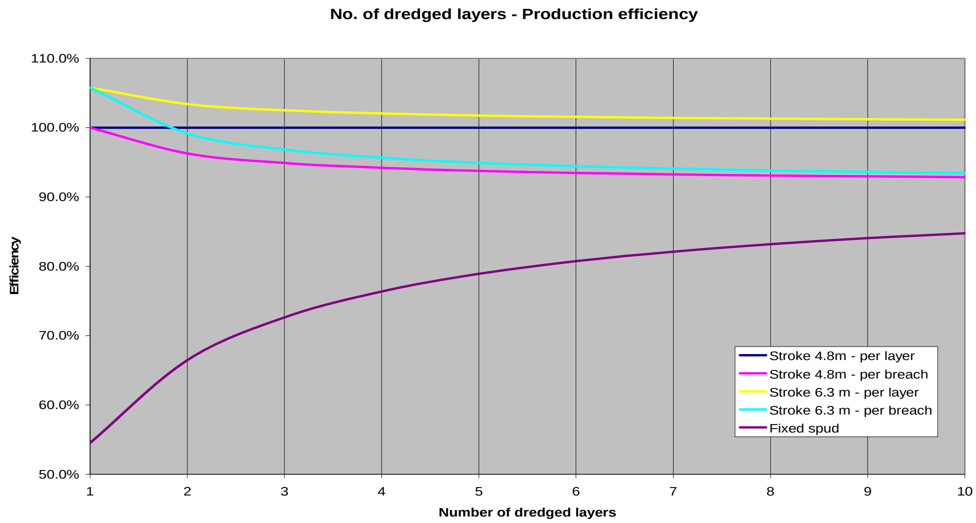


Figure 15: Relative efficiency of spud installation.

Influence on Delivery Time

Engineering

The IHC modular design approach for cutter suction dredges has the advantage that engineering time needed for the construction of the range of available components can be considerably reduced. This, however, is only possible when these components can be used without requiring any modification due to additional requirements from the client. It is obvious that the more a ‘new‘-design resembles an existing dredge the more reduction can be achieved in the engineering effort.

The modular approach is used for the first design of a dredge and the selection of the main components. As long as the various combinations of components have not been fully detailed up to production stage and could be labeled ‘standard’, a considerable engineering effort is still required. As these dredges are often constructed in co-operation with and on the location of shipyards all over the world the following issues have an impact on the engineering effort:

- Selection of main equipment like diesel engines
- Requirements of Classification Societies and Local/National Supervisory Authorities
- Available or preferred materials for hull construction like dimensions and thickness’ of plates and profiles
- Selection and interfacing of locally purchased equipment with the dredging equipment
- Demarcation of supply between shipyard and dredging component supplier
- Quality control
- Production standards and procedures

Hardware

The selection of standard components will allow the supplier of the dredging equipment to start production directly after receiving an order with only minimum time required for engineering. The delivery time for components will therefore be determined by the delivery time of long-lead items and the required construction time and the availability of production facilities.

When series of modules are sold or are likely to be sold and therefore a larger volume of certain long-lead items is required, it becomes economically viable for IHC to take certain of these items on stock. This is being considered and might allow for relatively short delivery times even in times of high demand and low supply.

Influence on Dredge Construction

In the modular design concept one of the design considerations was that the dredges are constructed locally. This has impacted in the arrangement and lay-out of components and equipment of the dredge. A few examples are:

- Booster Pump Modules are placed on the main deck.
  - Dredge pumps can be installed in a relatively late stage of the construction of the dredge.
  - The dredge pump is easily accessible for maintenance. Water and soil coming from the dredge pump when opening up for maintenance can easily be discharged over the side. The deck cranes can assist during maintenance with considerable hoisting height and can easily transport parts to auxiliary craft when required. Working conditions for crew during maintenance in cold climate may be less favorable.
  - Increased safety due to the fact that there are no dredging lines penetrating the hull around or below the waterline which through which flooding could occur in case of rupture.
  - When dredging is done without the ladder pump, the production is reduced more.
- Ladder Trunnions are placed above maindeck level.
  - The placing of the ladder trunnion above main deck level is a logical result for the selection of placing the booster pumps above maindeck and allows for a smooth transition of the dredging line from the ladder to the pontoon and the booster pump.
  - The ladder trunnion points are considered critical tolerance areas. By placing the trunnions on the maindeck the tolerance problem has been eliminated from the process of the construction of the hull. The better accessibility of the trunnion point constructions during their alignment and mounting makes it easier to accomplish this task.

Figure 16: Ladder trunnion construction.

- Hydraulics in spud carriage.
  - The hydraulic installation for spud hoisting of both working and auxiliary spud as well as for the spud carriage movement installed in the body of the spud carriage as much as possible. This allows for flushing and some testing of this part of the hydraulic system prior to delivery.
- Accommodation Module.

– The Accommodation Module is arranged as a separate module which is mounted on rubber supports on the maindeck of the pontoon. This improves the habitability for the crew and allows the unit to be separately constructed and outfitted before mounting on board. The Dredge Operator Cabin is constructed in a similar manner.

EXAMPLES OF ACTUAL BUILT DREDGES

Dredge Operation

The first dredge in the 7525MP series was delivered in February 2005 and the first dredge in the 7025MP series was delivered in January 2006 with the second one following in August 2006. Presently all three dredges are successfully operating in the Tianjin region in North China.

Figure 17: CSD "Fu Min 9 Hao" (7525MP type).

Figure 18: CSD "Beiya 1 Hao" (7025MP type)

Figure 19. CSD "Gang Hang Jun 8" (7025MP type).

Table 1. Overview 7025MP design variations.

Dredge	Cutter Module	Spud Module	Pump Module	Barge Module	Accommodation
1	Cutter	Stroke 4.8m	Standard		12 persons
2	Cutter	Stroke 4.8m	Standard		12 persons
3	Cutter + Wheel	Stroke 4.8m	Standard	Length + 2.10m	21 persons
4	Cutter + Wheel	Stroke 4.8m	Standard	Length + 2.10m	21 persons
5	Cutter	Stroke 4.8m	Standard	Length + 2.10m	21 persons
6	Cutter	Stroke 4.8m	Standard	Length + 2.10m	21 persons
7	Cutter + Wheel	Stroke 4.8m	Standard	Length + 2.10m	21 persons
8	Cutter + Optional Wheel	Stroke 6.2m	Standard		13(+2) persons
9	Cutter + Optional Wheel	Stroke 6.2m	Standard		13(+2) persons
10	Cutter + Optional Wheel	Stroke 6.2m	Standard		13(+2) persons
11	Cutter + Optional Wheel	Stroke 6.2m	Standard		13(+2) persons
12	Cutter + Optional Wheel	Stroke 6.2m	Standard	Length + 2.10m	21 persons

In the table above an overview of the present series of 7025MP dredges is given, delivered or presently under construction with the various combinations of modules and changes on modules.

CONCLUSIONS

This paper documents how a modular approach was used in the design of a specific cutter dredge series. By analyzing the design criteria and selecting the appropriate available modules allows a suitable combination of modules to be quickly selected. It is explained how various modules can be combined and how the combination of the modules should be analyzed. With the expansion of the range of available modules the number of possible combinations of modules increase and this will enable the designer to select the best possible lay-out of modules for his design in order to meet the requirements of the client. The variation of modules or number of modules in a design concept can expand the working range of a dredge design. The modular approach is limited in optimizing the dredge design for a single optimum working point at a particular dredging location by the availability of modules.

The modular approach for cutter suction dredge design has proven to be a versatile and flexible design concept which supports the production and analysis of cutter suction dredge designs in a short time. It has proven to be an efficient and successful tool in developing design variations for a series of dredges in response to request from our clients.

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