THIRD GENERATION ROCK CUTTING SYSTEM FOR CUTTER DREDGES WITH 3000-6000 kW CUTTER POWER
FIELD RESULTS

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ABSTRACT

VOSTA LMG's concept for a new system was launched during the Europort 2003 and is since then tested on several cutter dredges in different kinds of hard soil. This paper describes the field results, experiences from the crews and the modifications made to improve the product even further.

Keywords: Operational time, Tooth replacement, Safety, Cost savings

INTRODUCTION D2000-T6

This (patented) third generation cutting system was introduced to the dredging industry on the EUROPORT exhibition in Amsterdam in November 2003. The system is clearly described in the paper "Third generation rock cutting systems for cutter dredges with 3000-6000 kW Cutter Power" by K.G. Wijma.

The most important differences between the new system and the second-generation systems were:
- The teeth have a lower weight which is especially important for the new jumbo cutter dredges where teeth of the second generation weigh more (>27 kilogram) then the crew can handle manually.
- The lockings can be replaced easily using a standard power tool, instead of using sledgehammers to knock out locking pins. This means very fast and safe replacement of teeth.

There were also some other advantages:
- Tooth can be forged and casted, which optimizes the production capacity, which can be of great importance in times when there are plenty of rock jobs for the dredges and thus fast quantities of teeth are needed.
- It was expected that the spillage would be reduced with approx. 5% due to the special design of the teeth and adapters, which is optimizing the scooping effect and guides the material to the suction mouth without obstructions.
- Longer operational time of the cutterhead on the dredges, before it has to be removed due to cracked or broken adapters.

During that exhibition the first test with Dredging International in the Bahamas had just started. This paper describes the results of that test and of some other tests that followed.

Note:
With first generation systems is meant: VOSTA (Stapel) S10-S20 and D20-D35 series, ESCO 24D-54D series, FMF 3"-6"series
With second generation systems is meant: VOSTA SC10-SC60 series, VOSTA D40-D65 series, ESCO 28D-68D series
With third generation systems is meant: VOSTA T system

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TESTING

VOSTA LMG insisted on extensive testing before releasing the T-system to the market. This was for three reasons.

1. Many new promising tooth systems failed in the real operating conditions. As it is very expensive to produce patterns/tools for cutterheads, teeth, adapters and lockings for serial production, so called prototypes were used to verify that there were no hidden errors.
2. With the feedback from the users the system can be modified to their wishes and finalized for serial production. In this way the end users get the product they like without the trouble of growing pains or modifications which are typical for newly launched cutting systems.
3. To check that the system complies with all the parameters set. For the T-system extensive lists of criteria were set up. Theoretically the new system complies with all. Operation in the conditions the system was designed for is the real judge.

THE TESTS

Until now there have been three different tests on different locations. The T-system has been tested in extreme hard rock, normal rock and packed sand also some clay was encountered. The tests themselves varied from short comparison tests in direct comparison with second-generation cutterheads to long endurance tests.

TEST 1

Site	Freeport, Bahamas
Dredge	CSD Amazone
Owner	Dredging International
Cutter power	4000 hp

Description of the job:
Deepening the harbor and entrance of Freeport. The soil was extremely hard. Several boreholes had a UCS higher then 60 Mpa, which normally is beyond economic dredging. Against everybody's expectations the T6 cutterhead survived these conditions with only one broken adapter after more then 25 days of operation, whereas the conventional cutterheads lasted just a few days in the same hard conditions. Then typically they had 2 broken adapters and 4 more cracked.
Goal of this test was to prove that the new system was the best selection for Dredging International's new jumbo cutterdredge with 28000 kW. As the outcome of the test was very positive, the new dredge will be equipped completely with T6 and T8 cutters. The T-8 cutter is now probably the strongest tooth system available on the market for dredge cutterheads.

TEST 2

Site	Parsport, Iran
Dredge	CSD Ursa
Owner	Boskalis
Cutter power	5000 hp

Description of the job:
Deepening of the newly developed harbor and supplying bottom material for the breakwater. The soil mainly consisted of cap rock with softer layer of cemented sand below. The VOSTA T6 cutterhead was mounted for approx. 6 weeks and needed no repairs at all when the job was finished. Only one tooth was recorded broken. Goal of the test was to prove to Boskalis the benefits of the new system. Upon the successful test Boskalis modified this cutterhead and some other completely to T6.

Figure 2. VOSTA D65 test cutterhead equipped partly with T6.30 tube adapters (prototypes)

TEST 3

Site	Jubail, Saudi Arabia
Dredge	CSD Taurus
Owner	Boskalis
Cutter power	5000 hp

Description of the job:
The T6 cutterhead was used for two weeks in hard and abrasive cap rock. Here the newly developed twin adapters were used for the first time. On a total of almost 2000 teeth consumed 15 teeth were broken and one twin adapter had to be replaced.
The twin adapter cracked due to internal cracks. This adapter was a sample that was rushed in for testing and for which the casting- and heat treatment process was not optimized yet.

TEST 4

Site	Pars, Iran
Dredge	CSD Aquarius
Owner	Dredging International
Cutter power	2500 hp

Description of the job:
Deepening the service harbor. The soil consisted mainly of a cap rock layer with cemented sand and gravel below it. The cutterhead used was earlier used in the Bahamas by the dredge Amazone (see test 1).
One adapter on POS 1 was broken and another adapter was ripped off. Most likely cracks already initiated in the Bahamas caused the adapters to break. No broken teeth were recorded after approx. 8 weeks of operation.

SUMMARY TEST RESULTS

The most remarkable results were:

- Easy replacement of the teeth
- Reliable functioning of the locking
- Self flushing effect on the locking and tooth
- Positive acceptance by the crews
- Long lifetime of the adapter
- Longer life time of the tooth
- Reduced spillage of the cutterheads

Easy replacement of the teeth

In the beginning many people were quite skeptic about the new method of replacing teeth. They did not believe that changing teeth could go much faster and easier than the conventional way using hammers and pins. This changed very quickly when the crew became used to the new method and saw the advantages of the airtool doing the heavy job and the lightweight (13.5 kgs instead of 18 kg) teeth which were much easier to handle. Tooth replacement times dropped with 30-50%.

Figure 3. Airtool (weight approx. 1.5 kg) and locking

Reliable functioning of the locking

The lockings were unexpectedly reliable and endurable. Practically zero losses of teeth were recorded, whereas incidental loss of teeth is considered as part of normal operation (in hard soil). The average lifetime of the locking was above 30 teeth per locking, against less than ten for the conventional pins. Later improved lockings will achieve even higher ratios.

VOSTA LMG expected that there could be problems with the lifetime of the forged locking hook part due to its constant movement in a sandy environment. The outcome was that the wear on this part was negligible.

Self flushing effect of the locking and tooth

The locking was designed in such a way that it would always function, even in the worst imaginable conditions. A special test rig was fabricated in the development phase of the system to simulate the movement of the locking in extreme situations (see figure 04). For instance when there is a lot of space on the rear side of the teeth. One of the other extreme situations is when the locking and its recess in the adapter are completely filled up with sand. Tests showed that the locking would still work in these conditions.

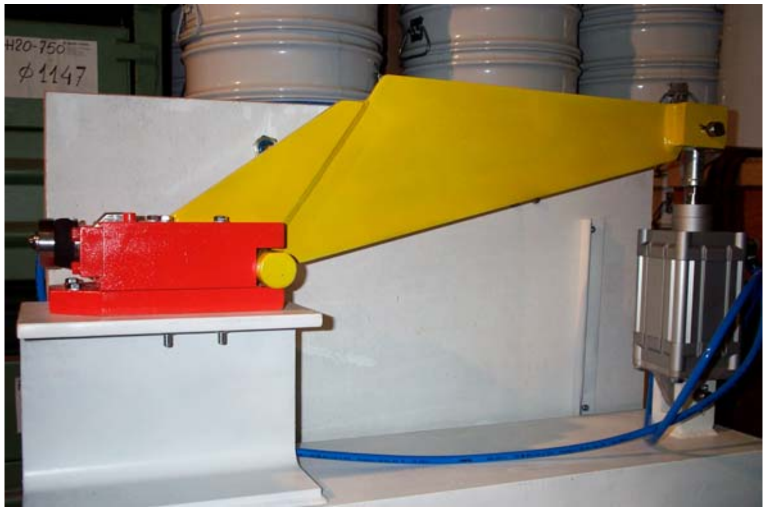

Figure 4. Test rig for locking

The ultimate test was when the locking and adapter recess were filled with so-called Portland cement. From experience we know that there are soils in the world of which the grains will cement together as soon as it dries up. Also here the lockings still functioned although some light hammer blows were needed to get the lockings loose from the teeth. Therefor it was a great surprise that the locking always was clean when the cutterhead was lifted. No matter what kind of material it had been dredging.

Now we know that this is caused by the open slots on the topside of the adapter, which allows water to come in. The water leaves the adapter on the rear-side, flushing along all sides of the locking. Minimum rotational velocity of the adapters through the water is approx. 1.8 m/s. Maximum rotational velocity is approx. 6.7 m/s. This creates sufficient flow for the flushing.

Figure 5. Top view on adapter showing the slots that create the flushing effect. The few small particles in the open slots have no influence.

As the open spaces between tooth and adapter are flushed, there is no material which can cement to the tooth or adapter, which can lead to a situation that the tooth cannot be replaced any more. During the test in Iran and Jubail this problem occurred on some conventional cutterheads. The teeth had to be replaced using flame cutting equipment or extreme hammering.

Acceptance by the crews

Especially with the international contractors the crews are the toughest critics. In the end they have a big influence on the decision which cutterhead will be used. It is their job to achieve maximum productivity with their floating excavating machine and will use the tools, which they consider as the best for the job.

Therefor it was a confirmation of the potential of the T-system that all crews favored the third generation cutterhead over the conventional ones (although they were skeptical at first about the locking system).

Long life time of the adapter

The operational time of the cutterhead at least doubled compared with conventional systems. This can be explained by the following (see figure 06 and 07).
The conventional systems have the highest wear on those surfaces, which also determines the axial position of the tooth. The tooth is only allowed to move a few mm‘s axially, otherwise the locking will not have enough pretension and will be lost resulting in losing the tooth and damaging the adapter.
In the new system the maximum wear is on other surfaces which are not critical for the axial position of the tooth. Furthermore the design of the locking is such that it will always have sufficient pre-tension. Even if the teeth would go backward 5 mm.

Figure 6. Wear on front stopper resulting in reduction of pretension on the locking

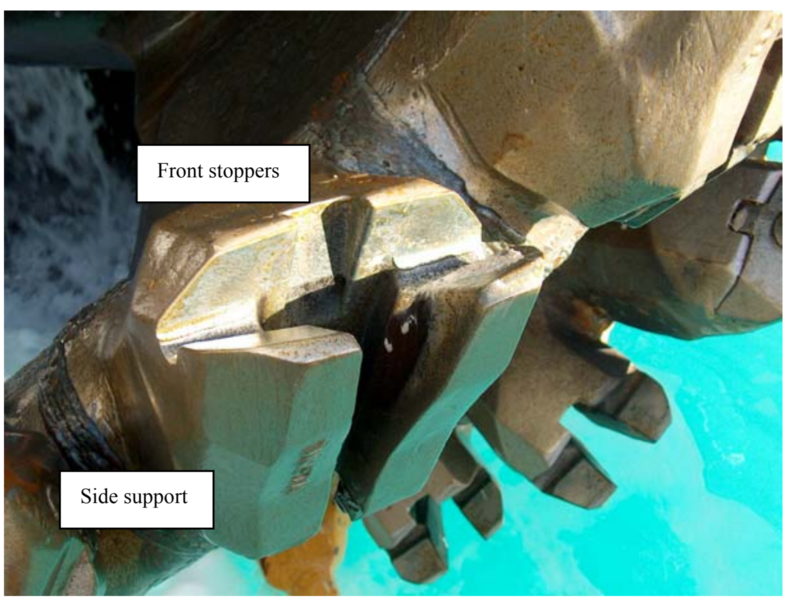

Figure 7. Negligible wear on the front stopper of the T6 adapter

Another reason for the long life time from the strength point of view is the fact that the side supports of the adapter see only a load in one direction unlike conventional systems that also see a load in the opposite direction (so-called cyclic load). From the fatigue point of view the first is much better for the lifetime.

Reduced spillage of the rock cutterheads

Although the companies that tested are reluctant to give any percentages, the difference was big enough for operators and some surveyors to admit that the spillage was significantly reduced.
As differences smaller then 5% are hardly noticeable we have to assume that the difference was at least around that value, and thus complying with our expectations.

ECONOMICS

What does this all mean for the users? Apart from the safety aspect related to the hammering, the economic benefit is a fact. This benefit varies from 10% up to 50% depending on the type of job when all cost is considered. Two of the most important cost reducers are the wear life of the teeth and the replacing time needed. The more teeth are consumed per day, the more important this becomes.
The graph in figure 08 shows the improvements on the dredge efficiency for three different situations:

Situation 1

Operational time of the conventional cutter is 4 hours, tooth replacement time 30 min. vs respectively 4h48m and 20 minutes for the T6 cutter. The production increases from 885 m^3/hr (1) to 935 m^3/hr (1'). Additional production increase due to lower spillage results in an improved output of 982 m^3/hr = **+ 10%**

Situation 2

Operational time of the conventional cutter is 60 minutes, tooth replacement time 25 min. vs respectively 72 and 17 minutes for the T6 cutter. The production increases from 705 m^3/hr (2) to 808 m^3/hr (2'). Additional production increase due to lower spillage results in an improved output of 848 m^3/hr = **+ 20%**

Situation 3

Operational time of the conventional cutter is 30 minutes, tooth replacement time 20 min. vs respectively 36 and 13 minutes for the T6 cutter. The production increases from 600 m^3/hr (3) to 735 m^3/hr (3'). Additional production increase due to lower spillage results in an improved output of 771 m^3/hr = **+ 28%**

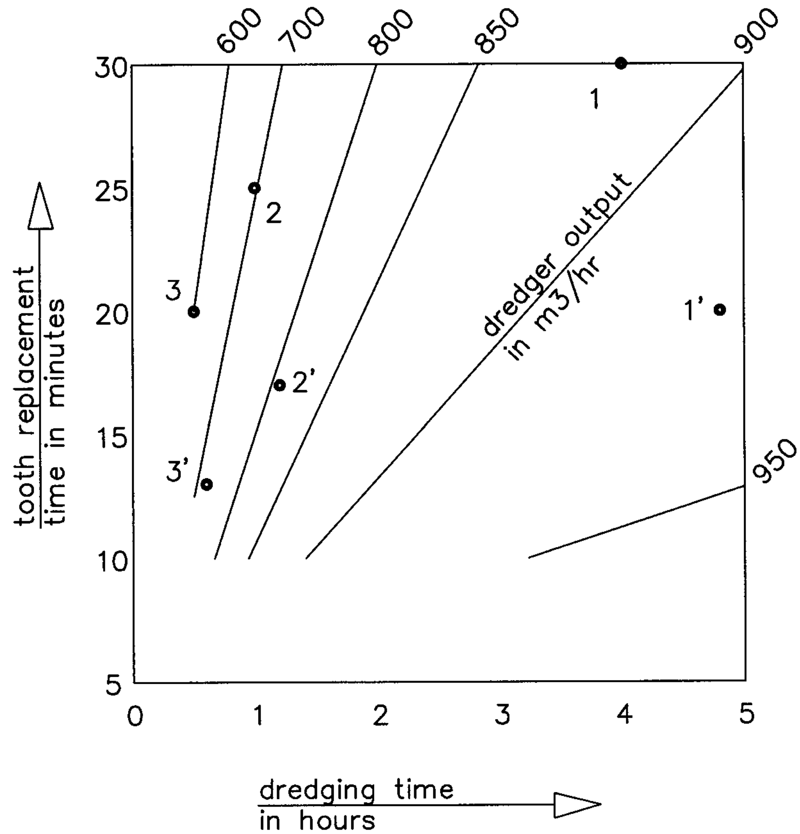

Figure 8. Output dredger vs teeth replacement time and dredging time

The figures are based on an output of 1000m³ of rock per hr when continuous excavating and the following realistic improvements:

- The life time of the teeth improved with 20%.@
- The output of the dredger improved with 5% due to less spillage.
- The time for replacing teeth reduced with 33% @ .The downtimes indicated include also the hoisting and lowering of the ladder which are the same for both systems.

@ = in comparison with the most commonly used second-generation cutterheads.

Maintenance cost which is also significant is not considered in this comparison but for the T-system this is much lower compared with the conventional systems.

MODIFICATIONS/IMPROVEMENTS

During the test an enormous amount of data was gathered, part of it was the recording of all damages / incidents / wear which is very valuable information for improving the system. Damages are broken, cracked or ripped of adapters or teeth and bended or destroyed lockings. Incidents are lost teeth or not properly functioning of the locking, stuck teeth. With wear we mean the amount of wear on the adapters, teeth and lockings on other surfaces then the tooth points This information is used to improve the product.

Overview of damages

Teeth consumed	8000 approx.
Adapters broken	2
Adapter ripped of	1
Adapter cracked	1 sample with initial cracks
Adapters repaired	0
Teeth lost	0
Teeth broken	30 approx.

Broken teeth

During the tests several teeth were broken (point broken off or cracked) under hard excavating conditions. This is OK as it will protect the cutter against overload and the remaining part is still protecting the adapter.

Figure 9. Tooth broken in the coupling part

However some teeth were found broken in the coupling part of the adapter, which is not favorable as such a tooth does not protect the adapter anymore. Investigation showed that this happened at extreme overloads (much higher then the design loads) with partly worn teeth. With new teeth the point would break and not the lower part. Investigation of the breakage showed also that the cracks started at spots with high stress concentrations (see figure 10). By changing the radii at the critical spots, the tooth bottom part has become much stronger.

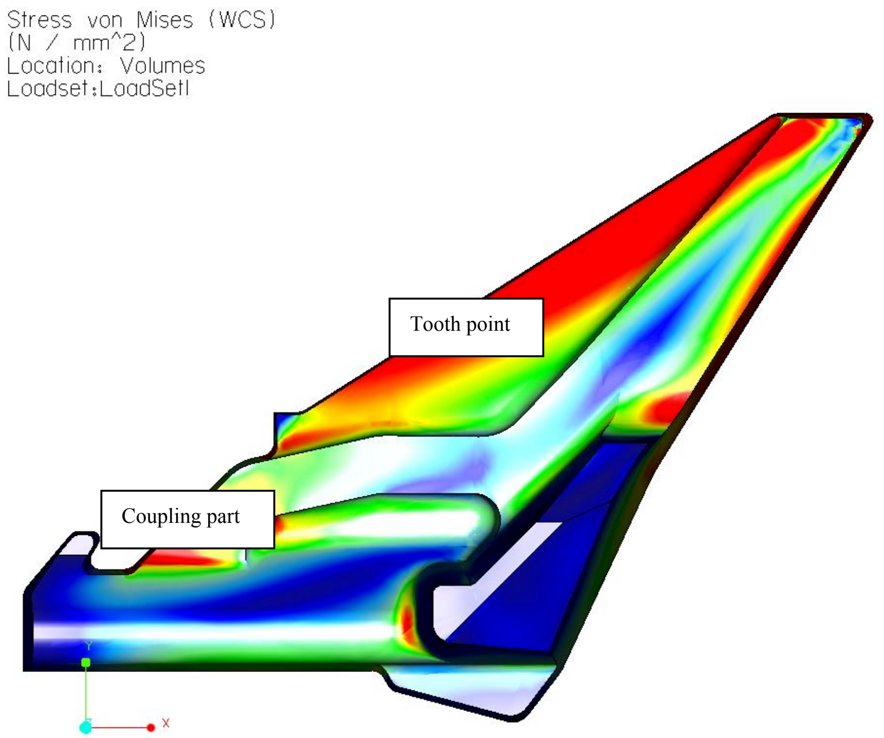

Figure 10. FEM analysis showing the stress concentrations in the coupling part of the prototype tooth.

Lockings

Several lockings were damaged on the rear side. The ring was bended and the rubber damaged. (see figure 11). This was probably caused by big rock parts, which had another direction then the majority of the material flow. Although this did not jeopardize the functioning of the locking, it was reason enough to strengthen the ring and lower the recess of the locking to get it more in the shade of the adapter and teeth. A new one can now easily replace the rubber element when it is damaged.

In 1,5 year of operation zero teeth were lost, making the system extremely reliable. Furthermore the remains of all broken teeth were still in the adapter which gave valuable feedback about where the teeth were breaking. With 2nd generation systems it was rarely clear if teeth were broken or simply lost when the tooth was missing from the adapter.

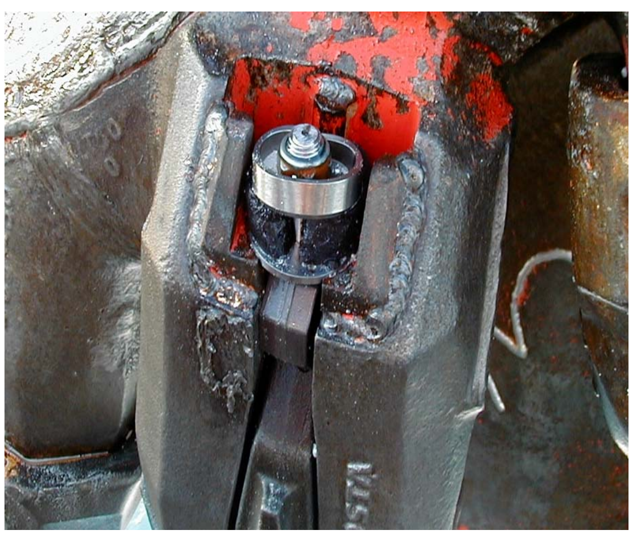

Figure 11. Showing damaged locking ring and rubber

Adapter

Two tube adapters were broken due to overload as per figure 12. FEM analysis showed that there are high stress concentrations in the area where the crack started. The radius in this area is now increased to reduce the stresses. One adapter was ripped of from the blade. All these adapters were on POS 1 and will be replaced by the stronger TWIN adapter.

Figure 12. Showing the broken side support of the adapter

Twin adapter

Brainstorming with the technical department of an end-user resulted in solving the thirty-year-old problem of the short lifetime of adapters on POS 1 when working in hard rock. (The top position is typical the worst place on the cutterhead for an adapter as it gets the highest loads, especially when stepping forward). The outcome was the TWIN adapter in which two teeth can be mounted. The twin adapter is used for the top position only.

It gives significant advantages:

- Much stronger weld to the blade. Normally the top position has the smallest weld (see figure 14)
- Optimum positioning of pos 1 and 2
- Improved opening between the arms
- Easier fitting of the top adapter.

Figure 13. The twin adapter for the teeth on POS 1 and 3

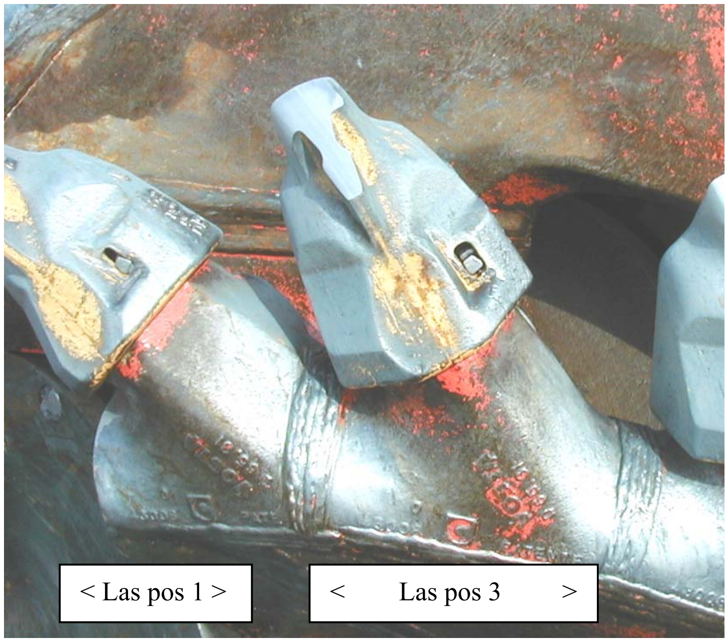

Figure 14. Showing relative short weld of the top adapter on a conventional cutterhead (left).

Wear

There are two kinds of wear on the cutting system:

1. Wear on the adapter outside
As VOSTA LMG has built up a good reputation of building completely freecutting cutterheads [2], it is important that the new generation cutting systems will be at least comparable. Especially when the swing speed is very high it is difficult to achieve this. Therefor it was very positive that until now there was no significant wear on the outside of the adapters even at high swing speeds.

2. Wear on the contact surfaces in the adapter
Although the system is designed to cope with significant wear on the contact surfaces (up to 5 mm), the reality is that the deformation of the contact surfaces is negligible until now. Even the adapters on the cutterhead that was used both in the Bahamas and in Iran, need no repairs on the contact surfaces.

CONCLUSIONS

The extensive tests under all kinds of conditions with the (patented) third generation VOSTA –T system has proven that the system is much more economical then the conventional systems, mainly due to the longer lifetime of the adapter and tooth and the fast and safe replacement of teeth. Until now it seems that only minor modifications are needed for finalizing the system.
Furthermore it has contributed significantly in increasing the safety of the crews who are replacing the teeth and making their work less hard.

REFERENCES

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K. Wijma and D. Petterson (1997) "Lowering the overall costs for the use of rock cutterhead systems", Proceedings CEDA Dredging Days 1997, Amsterdam, The Netherlands.

[2] Meaning that there is no direct wear on the adapters, blade, hub or back ring, resulting in a very long wear life of adapters and cutter body and no energy losses due to wear.