THIRD GENERATION CUTTING SYSTEMS–FROM FIRST IDEA'S TO A WORKING PRODUCT

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ABSTRACT

In 2003 VOSTA LMG launched a new revolutionary third generation tooth system called T-system. The development started in 1996 and it took till 2003 to complete the first prototype. This paper describes the design criteria, the development processes, the challenges in detail problems, the expectations and the actual results in the field. It also shows that a lot of 'out of the box thinking' and unconventional approaches were needed to come to a completely new concept that would bring cutting systems to a new level. Although the system was first designed for cutter dredgers with 5000 up to 8000 hp installed on the cutter shaft, smaller sizes have been designed for smaller cutter powers.

Keywords: Design criteria, locking design, low maintenance, unconventional approaches

INTRODUCTION

This new cutting system for big cutter suction dredgers was launched in October 2003 and has since then become operational on large scale. The advantages of this system and the philosophy behind it was described in the paper "Third generation rock cutting system for cutter dredgers with 3000-6000 kW cutter power" by K. Wijma presented at CEDA Dredging Days 2003. The experiences with the new system were described in the paper "Third generation rock cutting system; field results" by K. Wijma, presented at the WEDA conference in 2005.

The new tooth system size T6 was immediately successful from the first test in the field and meant a big step forward. It is now easy to point out the reasons why. Whether it is the low weight, the reliability, the fast changing of teeth, the possibility to upgrade existing VOSTA cutter heads or the long wear life, the result is the outcome of a long term project called "D2000". The real basis for the success was made during the development process.

The name for the design project was D2000. The D stands for dredge and 2000 for the new millennium.
For the name of the tooth system itself it was decided to keep it simple and stick to one simple letter T with one figure like 6. The T stands for third generation tooth system but coincidentally also for the T-shape of the slot in the adapter. The number 6 stands for the size which ranges now from T8-T6-T4-T2-T1-TSC04 and relates more or less to the maximum cutter power.

The purpose of this paper is to give insight in the design process and the most remarkable issues. It is only a part of the total picture as it will take a complete book to describe everything. Hopefully it will help others to come to new innovations as well.

HISTORY OF THE PROJECT

The D2000 project started in 1996 when VOSTA LMG supplied 4 heavy duty rock cutter heads type D65 to the CSD Castor for the job Öresönd. Due to the fact that this project took place geographically close to VOSTA LMG and that this was a long-term job with extreme tooth consumption, a lot could be learned by our engineers and specialists. After this project it was clear for VOSTA LMG that there was a need for a much more advanced system that would take away the disadvantages of the existing systems at that time, being:

- Weight of teeth is too high
- User-unfriendly and dangerous replacement of teeth (using sledge hammers)
- Short life time of adapter

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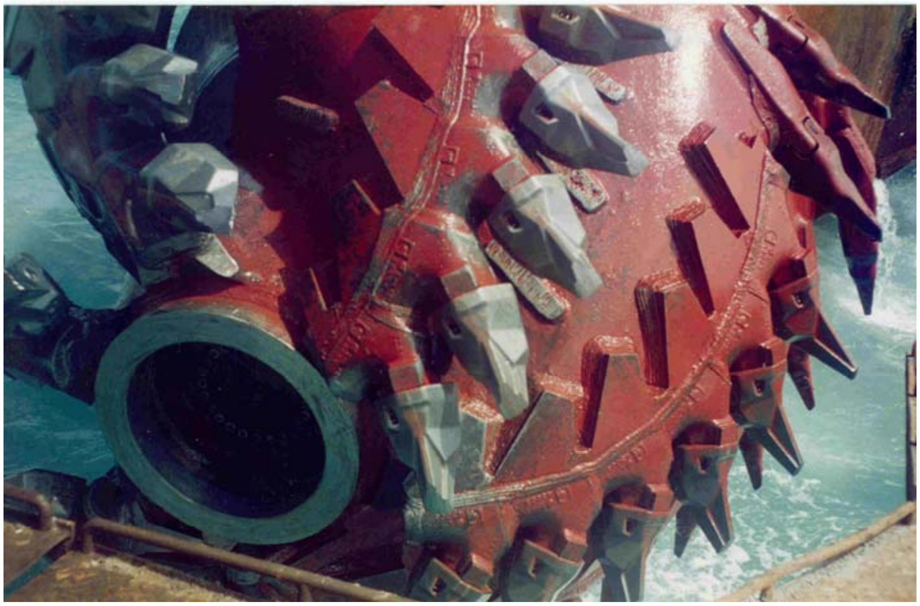

Figure 1. Test cutter head equipped with D65.

Especially the market demand of having a locking system that was hammerless was challenging and in the end also the most difficult to solve. Two of the most important initial tasks of the project team were to make an extensive examination of existing systems and to create lists of criteria for the design.

That the task of designing a new tooth system is very challenging is especially clear when considering that most of the tooth systems designed so far to meet the demand, failed technically or commercially. Only four systems out of the approximately 20 designs have become successful on a significant scale, and then typically after solving many start up problems. These successful systems are:

- VOSTA S10-S20, series ESCO 24-54D series, FMF 3"-4.5"series (all first generation type)
- VOSTA SC10-D65 series, ESCO 28-58D series (all second generation type)

Until 1999 several concept designs were created by VOSTA LMG for a third generation system. But none of them was able to comply fully with the criteria. Finally in the summer of 1999 a revolutionary concept design was made, which in potential could meet all criteria set.

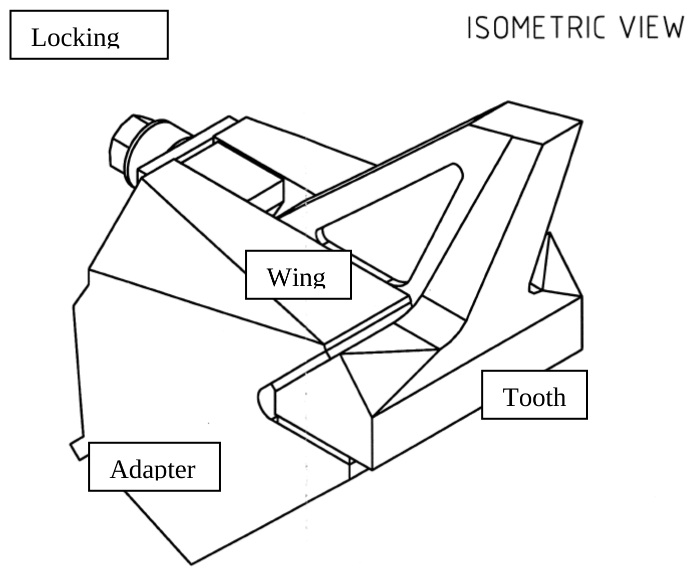

Figure 2. First concept (1999).

Based on this concept a business plan was written showing the cost estimates for further development of this system showing he potential benefits. After acceptance by the management the detail design was started and soon a problem was found in the strength of the adapter; more specifically the strength of the wings for the Fp lateral forces (this force acts on the point of the tooth perpendicular to the symmetrical plane of the tooth/adapter). This was so significant that unless it was solved it might have led to either a project stop or accepting a weak point in the design. Only in 2001 this problem was finally solved.

In the meanwhile the locking was developed. Dozens of locking designs were thought of and 16 were designed into detail. As the top three of the most promising locking designs were all situated behind the tooth. It was decided to create a black box area behind the tooth which was big enough for the proposed lockings and/or other alternatives. Thus the design of the locking and tooth /adapter could from then on be done independent to the development of the new system.

End of 2002 the design of the coupling geometry was ready, allowing the different types of tooth and adapters to be designed. These were ready around summer time 2003, waiting for the breakage tests to secure that the strength was correct. In the meanwhile the lockings were further developed, samples were made and tested. In the summer of 2003 the parts were tested on the breakage stand which showed that the different teeth, adapter and locking met the specifications. At the same time a world wide patent (PCT) was applied for. Autumn 2003 the first tests were done on the CSD Amazone in the Bahamas, which results exceeded all expectations.

Several modifications have been done since 2003 to make the system even better and this has continued till the spring of 2007. The total time frame from the initial thought to final marketing of a product has been eleven years!

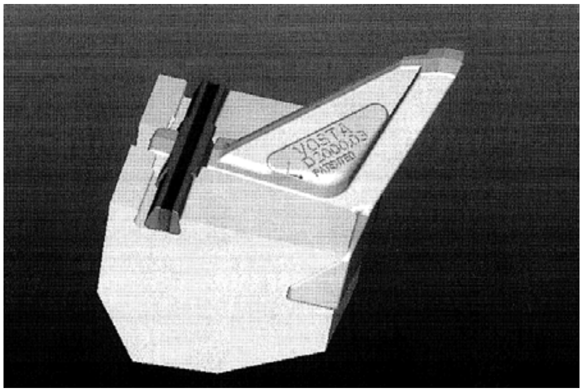

Figure 3. Alternative design with traditional locking.

Chronologic overview of the project

1996	start up
1996-2003	field tests
1996 -1999	gathering information & setting up design criteria
1999	first promising concept
2000/2003	detail engineering
2002	locking design was separated from tooth/adapter design
2003	first trials Bahamas
2004-2006	field tests, adjustments, modifications locking
May 2007	final design

THE PROJECT TEAM D2000

The members of the project team had to be carefully picked out. They had to fit in the team, bring added value and be aware of the importance of confidentiality. Secrecy during the project was paramount in order to be able to get a patent on the final concept as the competition never sleeps. A world wide patent is very costly but is needed to be able to earn back the huge development costs.

It was very important that the team could work in peace on the system and without time pressure. Therefore it was decided to have a time frame of 5 years for developing and producing the first prototypes ready for field tests. In the end it became 7 years.

In the 100 year history of VOSTA LMG (former company name: Stapel) this was by far the biggest research and development team ever and also the longest one in time. On its maximum the following people were included:

- Three CAD engineers
- One structural engineer
- Cutter captain / dredge operator
- Former (some retired) tooth system designers
- Patternmakers
- Production specialists
- Casting experts
- Two project managers
- Welding expert
- Patent lawyer
- Advisor

Examination of Existing / Old Systems

A full research was started in 1996 to get a complete overview of the strengths and weaknesses of other systems. This included calculating the contact stresses, failure analysis, gathering statistical data on damages like ratios of lockings used per teeth, teeth per adapter, life time adapter, wear length etc. Maybe even more important was to find out why other systems had failed in order to prevent to make the same mistakes. The most remarkable result was that the 'Number 1 reason' for failure was the locking.

Design Criteria

The team started gathering all the design criteria from 1997 on. Although the list was already very complete when it was released as the basis for the design, several new points were added in the years following as a result of the outcome of many tests during that period. It was unique that there were separate criteria lists made for the tooth system and the locking system. In the past the locking was typically integrated at the final stage of the tooth/adapter design. See appendix 1 for the complete list.

STRUGGLE WITH DESIGN PROBLEMS

During the design stage several problems surfaced that needed to be solved. In some cases real out of the box thinking was needed. It is estimated that approximately 15% of the work was normal engineering, but 85% of the time was brainstorming, conceptual thinking, discussions etc. Piles of sketches were created throughout the whole period!

Strength of the Adapter Wings

One of the concerns in the new concept was to make the wings on the adapter strong enough. Due to the complex load spectrum it is not possible to determine the exact design loads for the adapter. The design loads for the teeth were not the problem as these were identical for similar teeth of the existing systems.

The stresses in the existing type adapters could not be used for comparison as the shape and loading type is far different (the wings in the new design see no cyclic load like the old type adapters). When finally realistic design loads were known, it was clear that the wings would not be strong enough for lateral forces. Just simply beefing up the wings was not an option as this would give free cutting problems unless the teeth were beefed up as well, leading from one problem to the next.

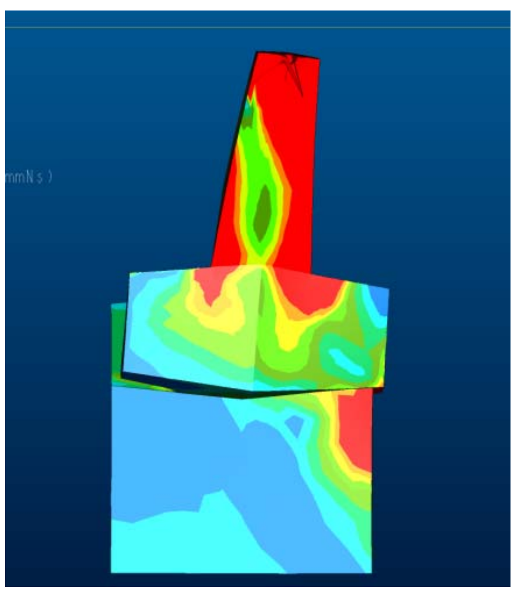

Figure 4. Original design (FEM calculations).

The final way to get around this problem was to add the bottom support which acts like a cantilever. Instead of a horizontal load on the wing it will create a vertical load on the front side of the wing (on the opposite side), for which the wings were designed anyway (FC = cutting force will create the same kind of load). Still many FEM calculations were needed to optimize the front side of the wings so that these would not become too massive.

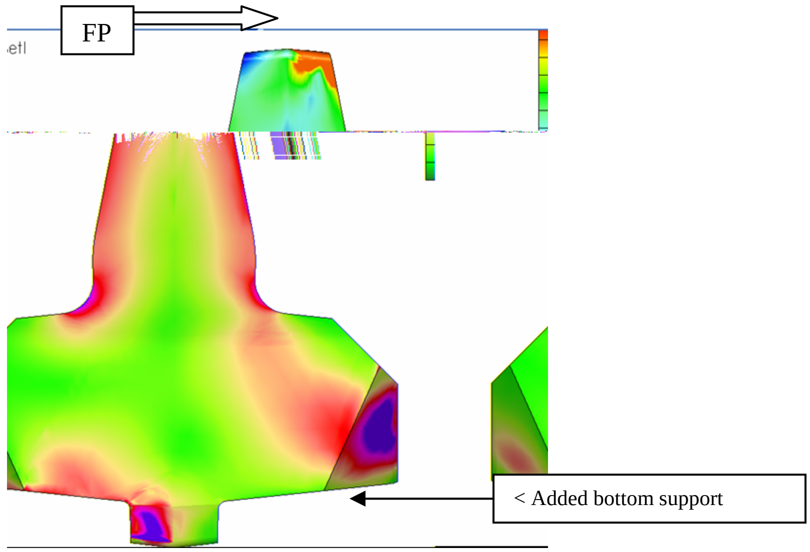

Figure 5. Modified design (FEM calculations).

Locking

From the three types of lockings that were selected and that all fitted into a predetermined box shape area on the rear side of the tooth, one was selected as the most promising. The concept of the selected one was not very different compared to the earliest concept drawing, demonstrating that sometimes it can take years to find out that the first idea was the best. But to comply with most of the criteria a lot of brainstorming and tests were needed. These tests included a vibration test (see Figure 6), corrosion tests, friction tests, cementing tests and movement test. All these tests showed that a lot of issues had to be solved to make the design perfect. In total the same amount of time was spent on the locking design as on the tooth/ adapter. In total several hundreds of different assemblies based on the same concept were designed and tested. Below follows some of the challenges that were faced.

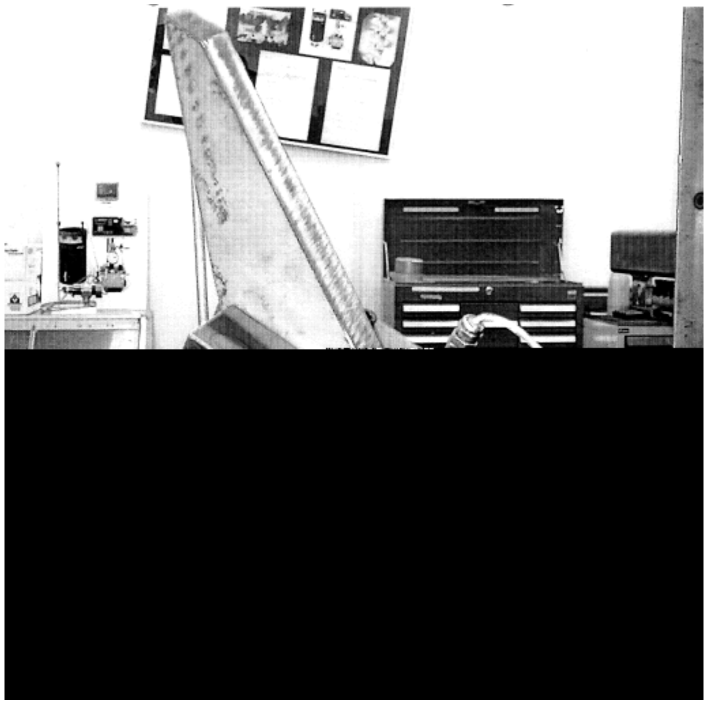

Figure 6. Vibration test of locking parts.

Material

One issue was to find out the right type of (stainless) steel material that could be forged (for a homogenous material), would be seawater resistant and also have a high strength. In the end special Swedish steel used for seawater resistant steel chains was an acceptable option. Another important issue to solve was the fact that due the pre-tension the nut would fret to the stainless locking hook very quickly when using power tools. Hundreds of tests were needed to find the best material for the nut. Bronze would be a logical option but is too weak and will create galvanic corrosion with the above material for the hook in seawater. Finally a high strength grade of AlNi bronze was used, which can be used almost unlimited with any tool and will also not corrode in this application.

Functioning Locking when Filled Up with Sand / Clay

The locking design had to be modified several times as well, as the tests often showed that the locking did not function properly when the area around the locking was filled up with sand, clay or cementing fines. Finally the design was so far optimized that during an actual test when the complete locking was bedded into hardened Portland cement it still could be dismounted without many problems.

Locking as One Unit

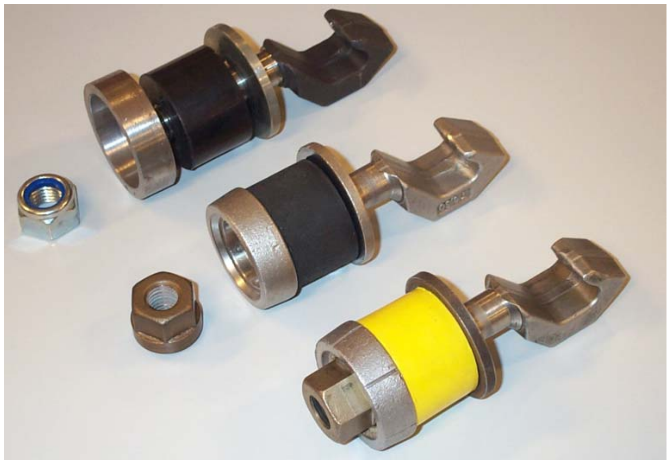

Figure 7. From top left to bottom right: first version to latest prototype locking.

Most difficult problem to solve was to make the locking as much as possible into one unit. Most of the designs fell apart in several pieces when dismounted (nut, rings, and hook). After one year of testing a locking design was accepted that falls apart in only two parts when dismounted: the nut and the locking. At this moment we are testing a version of which the nut is fixed to the locking hook so it remains one unit. Each part that might wear or get damaged on this locking can easily be replaced.

Wear and Tear

One of the other aspects for which the design had to be changed was the wear and tear that could be expected. No tests were possible except for the real operation on a dredger. One of the fears was that the holding point of the hook where there is moving contact with the tooth would wear out quickly due to the grinding action. In case this would happen the locking would be modified with a replaceable hardened steel front part (see Figure 8). In reality this wear never happened.

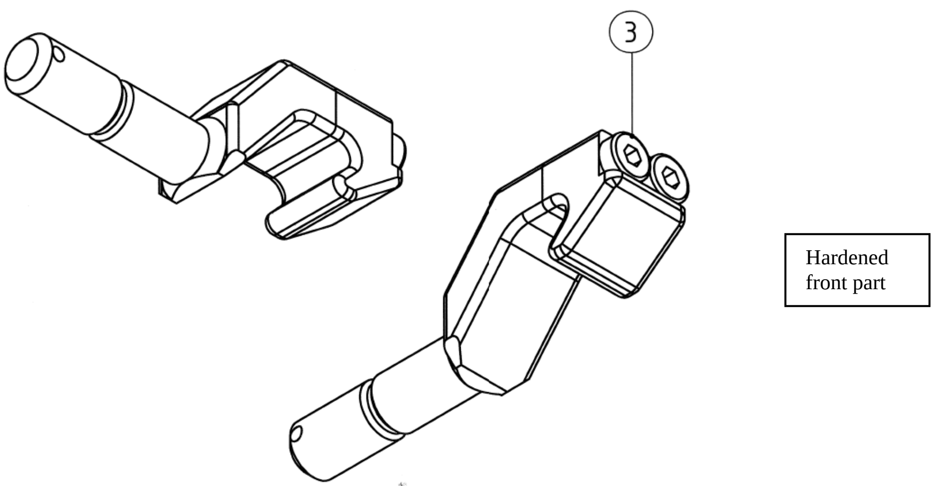

Figure 8. Locking wear resistant front part.

EXPECTATIONS AND ACTUAL RESULTS

Based upon the design there was a certain expectation what the outcome would be. The first operations with the T-system were closely monitored to see the results. Below follows some examples.

Strength T8

Figure 9. T8 cutter head installed on CSD d'Artagnan.

For CSDs with 8000hp on the cutter shaft like JFJ de Nul or d'Artagnan the forces on the tooth system are much higher then on the conventional dredgers with up to 5000-6000hp. Since the load spectrum on the teeth is very complex (especially in hard rock) it was almost impossible to calculate the design loads for the bigger T8 system. Based on the experiences with cutting systems for cutting hard rock for dredgers with lesser cutter power, it was however possible to extrapolate from there. The question was how T8 would really behave in tough conditions.

Until today the T8 system has had very little breakages or other technical problems when in use on the CSD d'Artagnan (together with the CSD JFJ de Nul the most powerful cutter dredger in the world). So it seems that the T8 system is properly designed for these extreme cutter powers. In fact it might be oversized. More statistic data is needed to determine its potential and to see if it is suitable for higher cutter powers.

Figure 10. Self propelled jumbo cutter dredger CSD d'Artagnan

Wear on outside of adapters

With the conventional cap type adapters of the second generation systems, the VOSTA cutter heads were completely free cutting in any type of soil. The unprotected surfaces on the new adapters are much bigger. Therefore it is very important that the angles and surfaces are such that the tooth front side is always free cutting the full adapter.

Whereas during the design stage the free cutting aspect was continuously in mind, the first two years of operation in hard rock and sand showed so little wear that free cutting was no longer a hot issue. However in 2006 some dredgers run into very abrasive soils (like soft rock mixed with clay with course particles) where immediately it became apparent that the T-adapters are less free cutting compared with the second generation system adapter. It however also showed that this has very little influence when the teeth have the correct positioning.

Wear on contact surfaces / life time adapter

If was expected that the contact surfaces would need repair (touch up) every 2 working weeks, against conventional adapters every week.

Figure 11. No visible wear after working in hard rock

During the trails the wear on the contact surfaces was closely monitored. On the front contact surfaces the wear is hardly visible. But after a long period (typical 4 weeks) these surfaces are so far worn that they have to be reconditioned to their original state. On the rear contact surfaces the wear starts to show immediately like a sharp edge. This reaches approx 0.5 mm and then almost stops. It will take a very long time before it reaches 5 mm when the bottom rear surface has to be repaired by welding. Since 2003 none of the adapters have been repaired on the rear surfaces.

Strength Adapter Wings

As previously described a lot of effort was spent to optimize the strength of the adapter wings. The expectancy was that cracks in the front radius would be the weak spot in the design. Reality is that only a few adapters failed due to cracks in that area. In general the adapter seems to be oversized. The lifetime is considered to be approximately 5 times higher then conventional adapters.

Weight

The target weight for a T8.04 tooth (pickpoint) was 20 kilograms, being the upper limit for frequent manual handling. During the design stage the weight shifted between 18 and 22 kilograms, so it was very exciting if the final tooth would comply with the target weight. But not only is the weight of the teeth important. Also how easy it is to pick up and how easy it slides into the adapter matters. The shorter the hands-on time is, the better. Therefore also a universal tooth holding rack was designed which can hold all types of teeth used and from which they can be easily lifted (see Figure 12).

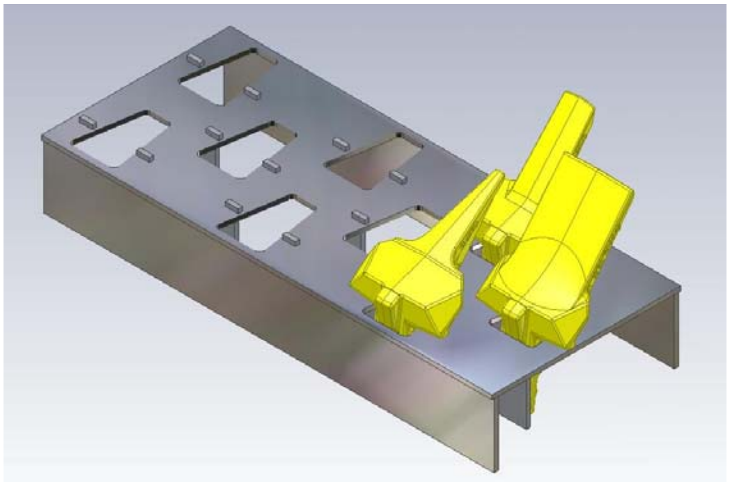

Figure 12. Tooth rack.

The serial produced rock teeth T8.04 weighs 19.5 kilograms and are thus acceptable for manual handling. The combination of the tooth rack and the easy access into the adapter are such that placing the teeth in the adapters is considered quite easy. Removing teeth is even better due to the fact that the amount of steel that can be worn away efficiently is large resulting in a much lower weight of the used part.

Locking Use, Wear and Tear

Most of the focus was on the functioning of the locking as this is the most critical part and for a big part determines if a tooth system is successful or not. We were afraid that the locking would be exposed too much to the rough conditions during excavation and therefore might wear out fast and on the other hand that the locking area would fill up with sand. Another question was: how reliable is the locking nut?

The locking functions very well. Lockings are very easy to mount and dismount. A single tooth can be replaced in less then 10 seconds. Also, all tests showed that there is very little wear on the locking. Only now and then the rubber has to be replaced. The locking has been extremely reliable; the amount of teeth in that are lost in three years can be counted on one hand. Sometimes locking nuts are lost during dismounting. This will be over with the latest design with the nut integrated in the locking.

CONCLUSIONS

The design of a successful new system for dredge cutter heads is a very costly, complicated and long term project. It needs a motivated and good managed team with a lot of practical experience, perseverance, a lot of problem solving power and also some luck. When everything falls into place a lot can be achieved. The T-system is the living proof.

Appendix 1

LIST OF DEMANDS FOR D2000

Tooth / adapter

1. Arrangement
Free cutting
Compact and strong
Suitable for sand/clay and rock tooth
Tooth easy and fast to replace on cutter
Operation in sand/ clay/ rock conditions
Operation in corroding condition
Suitable for scale up/down

2. Locking
See criteria locking design

3. Production
Tooth suitable for casting/ forging
Adapter by casting
Preferably no machining of adapter

4. Tooth strength
Side winch force FS
Cutting force FC
Perpendicular force Fp
low contact surface pressures
Low weight
Tooth breakage in case of overload
Wear length / area, identical to SC/D system

5. Adapter
Tube, wing and ring type
Easy repair of contact surfaces
Weight max 5 x tooth weight
Easy replacement of adapters
High fatigue strength
Weld area
Must fit on existing VOSTA cutter heads

6. Material
Adapter CNM90
Tooth CNM85

7. Protection
Suitable for patenting

8. Cost
tooth as low as possible
Adapter price max 10 x tooth price
new system must be more economical than existing systems

Locking

A. Construction
simple
strong
pre-tension
compact
low impact on strength tooth
low impact on strength adapter

B. Wear
Free cutting
Seawater resistant
Life time >2 x conventional locking
Insensitive for movement between
tooth and adapter
Good protected

C. Operation
Easy to use
Time to change teeth
Standard tools
Operation in sandy condition
Good ergonomics

D. Cost
Low cost locking
Low cost impact on tooth design
Low cost impact on adapter design

E. Reliability
No risk loosing teeth
Locking must function also when it is
Embedded in sticky- or cementing mat.
Low sensitivity for vibrations
very low risk of loosing locking
Temperature -10 to + 80 degrees