Metal stitch reconditioning analysis

Niklas Eurs

Bachelor´s thesis

Mechanical and Production Engineering

Vaasa 2013

ABSTRACT

Title: Metal Stitch Reconditioning Analysis

Author: Niklas Eurs

Supervisor: Andreas Gammelgård, Novia
Mats Lagström, Wärtsilä
Kennet Carlström, Wärtsilä

Date: 04-2013

Aim: Repairing a damaged engine block is a hard task, especially when the material is cast iron. Cast iron is difficult to weld and very brittle but yet so cheap and simple to produce compared to other metals, that it is hard to find a substitute when making large metal components. There are however methods for repairing cast iron, this thesis is for investigating where on Wärtsilä´s engine blocks, the repair method Metal Stitching can be used.

Method: Information from repaired engines on the field was gathered and evaluated. The location of the repair, running hours after finished repair and if any problems occurred during operation, have been interesting facts.

Another important aspect in this thesis has been the practical testing of the repair method. Test coupons were made of cast iron and stitched together with the Lock n Stitch method. The purpose of this was to see how much of the original strength remained after stitching.

Classification Societies´s comments, about their guidelines for approving these types of repairs, have been gathered.

Result & Conclusions: This thesis showed that only a fifth of the original strength remains after repairing. Despite this, the method is very useful in places on the engine block that are not directly affected by firing pressure or other highly loaded places. The strength of the repair is based on the remaining surrounding material and should therefore not be used for constructing. One of the benefits is that it can be done at site with minimal removal of components.

Suggestions for future research: The analysis continues with fatigue testing of repaired test coupons. The final result will be handed to Wärtsilä when fatigue tests are finished.

Contribution of the thesis: The results will be helpful when both Wärtsilä and its customers are deciding if to repair or replace a damaged engine block.

Key words: Metalstitching, repair, engine block, cast iron, tensile.

ABSTRACT

Titel: Metal Stitch Reconditioning Analysis

Författare: Niklas Eurs

Handledare: Andreas Gammelgård, Novia
Mats Lagström, Wärtsilä
Kennet Carlström, Wärtsilä

Datum: 04-2013

Syfte: Att reparera ett skadat motorblock är en svår uppgift, särskilt när materialet är gjutjärn. Gjutjärn är svårt att svetsa och är väldigt sprött men så billigt och enkelt att tillverka jämfört med andra metaller, att man inte vill frångå detta material vid tillverkning av stora metall komponenter. Men det finns metoder för reparation av gjuten, den här undersökningen har gjorts för att undersöka var på Wärtsiläs motorblock man med säkerhet kan använda sig av reparationsmetoden Metal Stitching.

Metod: För att uppnå önskat resultat samlades information, om motorer som genomgått sådan reparation av motorblocket, in från fältet. För dessa motorer noterades det var på motorblocket reparationen hade blivit utförd, driftstimmar efter reparation, om problem uppstått under drift efter reparation.

En annan viktig del av undersökningen har varit det praktiska testet av reparationsmetoden. Testbitar av gjutjärn tillverkades och sammanfogades med reparationsmetoden Lock n Stitch. Dragtest gjordes på testbitarna för att se hur mycket av gjutjärnets hållfasthet fanns kvar efter en reparation.

Klassningssällskapens kommentarer, om huruvida dylika reparationer godkänns, har samlats in.

Resultat & slutsats: Undersökningen har visat att en femtedel av hållfastheten kvarstår efter reparation. Denna metod är trots detta väldigt användbar på ställen på motorblocket som inte är direkt påverkade av tändtryck från cylindrar eller andra högt påfrestade områden. Reparationsmetoden baserar sig på omgivande material och bör därför inte användas för konstruktion eller nytillverkning. En av fördelarna med denna reparation är att den kan göras direkt på plats med minimal demontering av komponenter.

Förslag till fortsattforskning: Forskningen fortsätter med utmattningstest av reparerade testbitar. Resultat tillges uppdragsgivaren när utmattningstesten är avklarade.

Uppsatsens bidrag: Resultaten kommer att hjälpa både uppdragsgivaren och dess kunder när beslut skall tas om att reparera eller byta ut skadade motorblock.

Nyckelord: Metalstitching, repair, engine block, cast iron, tensile.

Table of contents

1 Introduction

I have been working for Technical Service at Wärtsilä since my first semester 2010 at Novia University of Applied Sciences. In late winter 2012 one of my colleagues from Wärtsilä called me and asked if I was interested in making my Bachelor´s thesis for them. The topic was at that moment Lock n Stitch and its working properties.

1.1 Background

Wärtsilä has thousands of engines around the world, both in power plants and ships. Every now and then an engine breaks down, either due to mishandling, material defects, poorly performed service works or mistakes. The result of these breakdowns can be devastating, such as severe damages to engine components or even worse, human injuries. If damages are caused to the engine, especially large cast components such as the engine block, it can be hard to repair, because cast iron is difficult to weld, possible but difficult. Cast iron contains a high level of carbon, which burns when welding. The concentrated heat caused by welding is causing expansion and contraction and leaving stresses in the block, which in worst cases can cause hardening and more cracks. Another problem when damages have occurred to the engine block is that the engine block itself stands for a third of the total weight and cost of the engine, and it is therefore hard to replace when built into ships and other facilities. This can result in large costs for the concerned people, especially when considering the price of a new engine block and the man hours needed to replace it.

These are the reasons why customers who have experienced damages to the engine block are repairing instead of replacing.

A repair method that is commonly used is metal stitching. Metal stitching is a cold repair method and by using different types of specially designed screws and locks, the cracks and damages in cast iron can be filled and replaced by new material.

The history of repairing cast iron with specially designed screws started in the 1930´s in Texas, USA. Oil production was in its expanding boom and new oil findings with oil reservoirs up to 140 000 acres were discovered. The oil industry was using a lot of mechanical equipment, and the demand for service and repairs of the equipment grew, and because it was in the oil industry, also the demand of fire safety grew. Because open flame and heat repairs such as welding and casting, could cause a fire, new repair methods started developing.

Figure 1. Oil plant in Texas.

Metalock

Three men, L.B. Scott, Fred Lewis and Earl Reynolds developed a method where cracks and other faults were repaired by drilling hole patterns across the crack and then filling them with hand crimped indentures (today known as locks and keys). In 1937 L.B. Scott secured patent rights for the repair technique and materials used. Scott started a franchising business under the name Metalock Corporation. In 1953 the patents expired and were free to use by anyone. Also during the time of patent protection new techniques and improvements had been developed for the method, and in 1953 the Metalock International Association was formed by a group of companies.

Lock n Stitch

In the 1980´s and 1990´s a new method based on the same principles was developed. The principles of Lock n Stitch method is to use specially designed screws, also called locking or stitching pins, to fill the crack in the casting. Also this method uses locks hammered into place in drilled hole patterns. The locking pins have specially designed threads and screw heads to enable a pulling force when torqued into place.

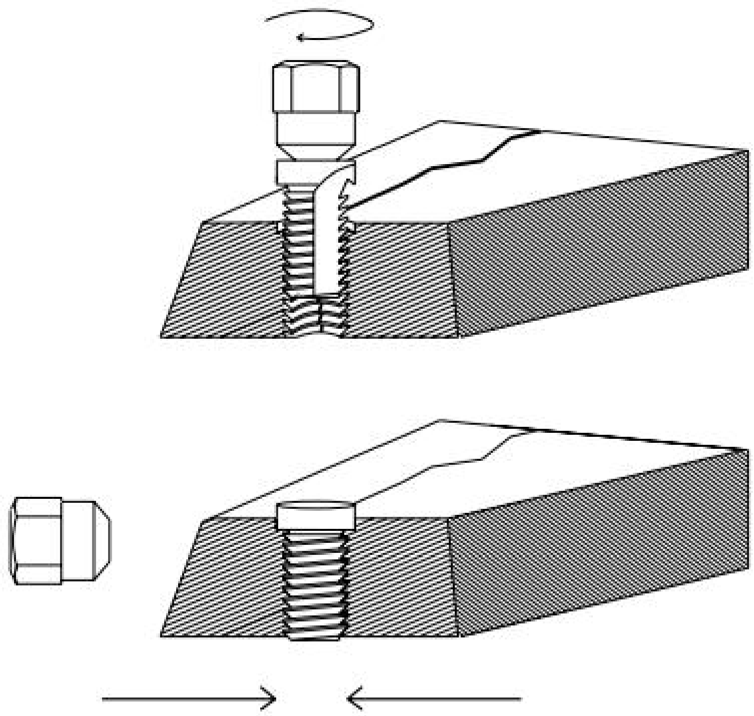


Figure 2. Lock n Stitch principles.

1.2 Purpose

Under this heading the purpose of the Metal stitch reconditioning analysis is described.

The main purpose of this thesis work is to gather as much feedback as possible from field installations that have suffered from damages to the engine block from either breakdown or other damages. The common factor for these installations is that they all repaired the engine block damages by metal stitching. By gathering this info and feedback Wärtsilä will be able to get a better overview of how successful the metal stitching repair methods actually are. This will be at help when Wärtsilä in the future is giving technical support about cases where metal stitching could be an option after an engine block damage.

The second purpose of this analysis is to more thoroughly investigate the actual strength of the metal stitching. This will be done by practical testing in form of tensile and dynamic testing. The wanted result of tensile testing is a value explaining how much of the original tensile strength still remains after a metal stitching repair. This knowledge will help when Wärtsilä gives technical support about where on the engine block it is possible to use metal stitching repair, as the stresses are not equal over the engine block.

1.3 Demarcation

Both Metalock and Lock n Stitch are companies offering a broad range of repair methods. Among their offered services you can find most of the machining and production concerned services, such as in situ machining, welding, thread repairs and so on.

However, this analysis is delimited to metal stitching, meaning, cast iron repairs performed by filling cracks and attaching new castings with locking pins, screws and specially designed locks.

Regarding the feedback research, the concerned engines are engines that are made, sold or serviced by Wärtsilä. The result of the feedback research will be a list of concerned installations and a Power Point presentation showing cases where stitching has been applied. Data from this list will be compared to a stress diagram of the engine block and by this the parts of engine block that can be stitched can be confirmed.

The testing of stitched components is limited to tensile tests of two different types of testing pieces. A fatigue test is limited to one type of test piece.

These limitations are made so that I will be able to perform the tests with more test pieces of each type and by that achieve a more reliable result.

1.4 Wärtsilä

Wärtsilä is the world leader in solutions for power plants and marine installations. The core of Wärtsilä are the engines. Wärtsilä produce, develop, service and sell large diesel and gas driven engines. Connected to these engines are large systems, everything from complete power plants to whole ships. In 2011 Wärtsilä had a net sale of 4,2 billion euros, operation in 70 countries and approximately 18000 employees.

The company is divided into three main divisions, Power plants, Ship Power and Services. Within these divisions there are several subdivisions, one of them is Technical Service, which is a subdivision under Services.

Technical Service

Technical service is a unit within Service. It is divided into several groups, one group for every portfolio engine, one group for condition based maintenance and several groups for expert services.

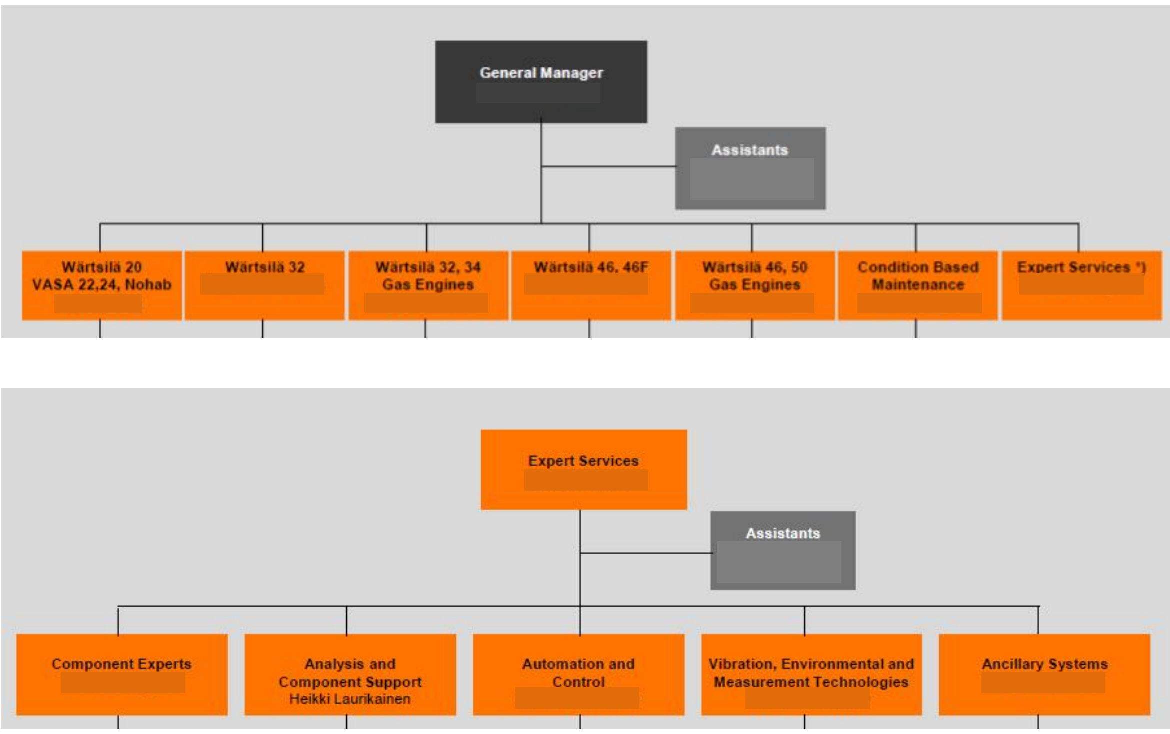


Figure 3. Technical Service organisation.

The main purpose of technical service is to provide technical support, for both internal and external customers, concerning technical matters such as technical problems and specifications for engines and ancillary equipment. Technical service performs on site investigations and root cause analyses, both during maintenance and when problems have occurred in the engine system.

The engine groups within technical service are also responsible for field tests of new designed and developed components and for being the initiators and makers of service bulletins for their concerned engine type. Engine groups also work as lecturers and experts in product related international seminars and other technical sessions and discussions.

To give an example:

A service engineer from technical service has given a lecture about the W32E engine in a sales promotion for Wärtsilä in a foreign country. On the way home he is going to visit an installation that has reported problems with their power plant and the staff cannot solve it themselves. The service engineer makes a site audit and gives his recommendations for solving the problem. The next day in office he/she answers questions about a problem that has occurred on an installation that is having an overhaul on their engine. The problem can be easily solved because last week the service engineer wrote a service bulletin about this actual matter.

1.5 Structure

The structure of my analysis was made up at an early stage of the project. The project was divided into three phases.

Phase one

- Agree on level of documentation and progress reporting.
- Estimate time schedule and milestones.
- Identify possible stake holders.
- Acquire feedback from concerned parts.
- Analyse the feedback.
- Contact classification societies about their requirements of metal stitching.
- Check with R&D for possible calculations.
- Plan inspection to a highly loaded installation with stitched engine block.

Phase two

- Field follow-up of selected installation.
- Specification of test.
- Arrange a tensile test of a repaired casting.
- Arrange a dynamic test of a repaired casting.

Phase three

- Summary of and suggestions for what can be stitched.
- Lesson learned review and closing of project.

2 Previous research

This chapter will process all previous research and knowledge I have had to learn and study to be able to accomplish my analysis with a credible result.

A lot of the previous research is based on work reports from Lock n Stitch and Metalock and service reports within Wärtsilä. By studying these reports I have been able to learn the ways of working and how the methods are applied when repairing an engine block.

2.1 Cast iron engine blocks

Wärtsilä W32 engine blocks are cast in one piece of spheroidal graphite cast iron. The standardized name in the European standard is EN-GJS-400-15.

A Vasa 32 engine block is cast from grey cast iron and the standardized name in the European standard is EN-GJL-250.

Grey cast iron is the most used cast iron and older castings are often made of this.

Spheroidal graphite cast iron is a more modern cast iron and has properties that are more useful for different usages. One welcomed property is that this material is more flexible and viscous. This property is accomplished by grafting the grey cast iron with ferroalloys. Before pouring, the cast iron is mixed with a small amount of magnesium. This makes the graphite flakes convert to spheroidal balls instead of flakes lying in a laminated way like in grey cast iron.

This property can be seen when comparing a Vasa 32 to a W32 engine that has been damaged, because the spheroidal graphite cast iron is more viscous, parts on the engine block that has been damaged can still be attached but are still cracked. On a Vasa 32 the damaged part often comes loose with a rather clean cut. Because of the fragility of the grey cast iron, also the tensile strength is lower in the Vasa 32 block.

2.2 Tensile tests

Tensile tests are done to materials when it is necessary to know their properties. Several different values of properties can be achieved by a tensile test. A test piece is put under successive increasing pulling load until the test piece breaks.

Yield strength, when a material exceeds its yield strength during drawing, the material can no more recreate its original length, the material becomes plastic.

Tensile strength, the highest tension a material can stand before braking.

E-module, useful during construction, E-module is a constant received from tension/strain.

0,2% proof stress, some materials may have very small or be absent of yield strength. In those cases yield strength is defined as the tension that, after tension relief, leaves a 0,2% deformation on the length of the material.

2.3 Dynamic tests

When tensile tests tell us about yield strength with static load, dynamic tests give a completely different truth. It has shown that when a material is exposed to dynamic tension, pulsating or changing, the material breaks at a much lower forces. This is called fatigue.

Endurance limit, defined as the highest tension a material can stand during unlimited times of load shifts.

2.4 FEM calculations on W32 engine block

Within the company of Wärtsilä FEM calculations of the engine block for a W32 engine have been made. These calculations were made to compare the stresses and displacements in a damaged engine block and a complete undamaged engine block. As load in these calculations, pre tightened cylinder head bolts and gas load similar to running condition are used.

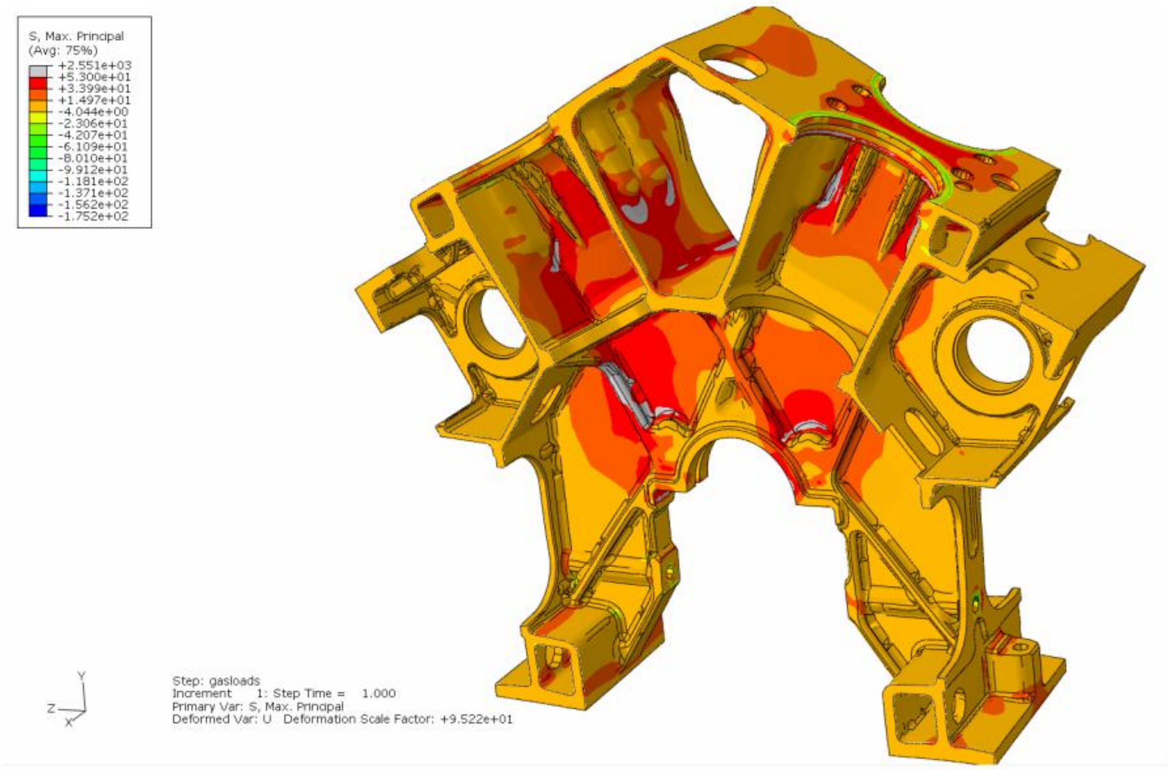


Figure 4. Maximum principal stress, general.

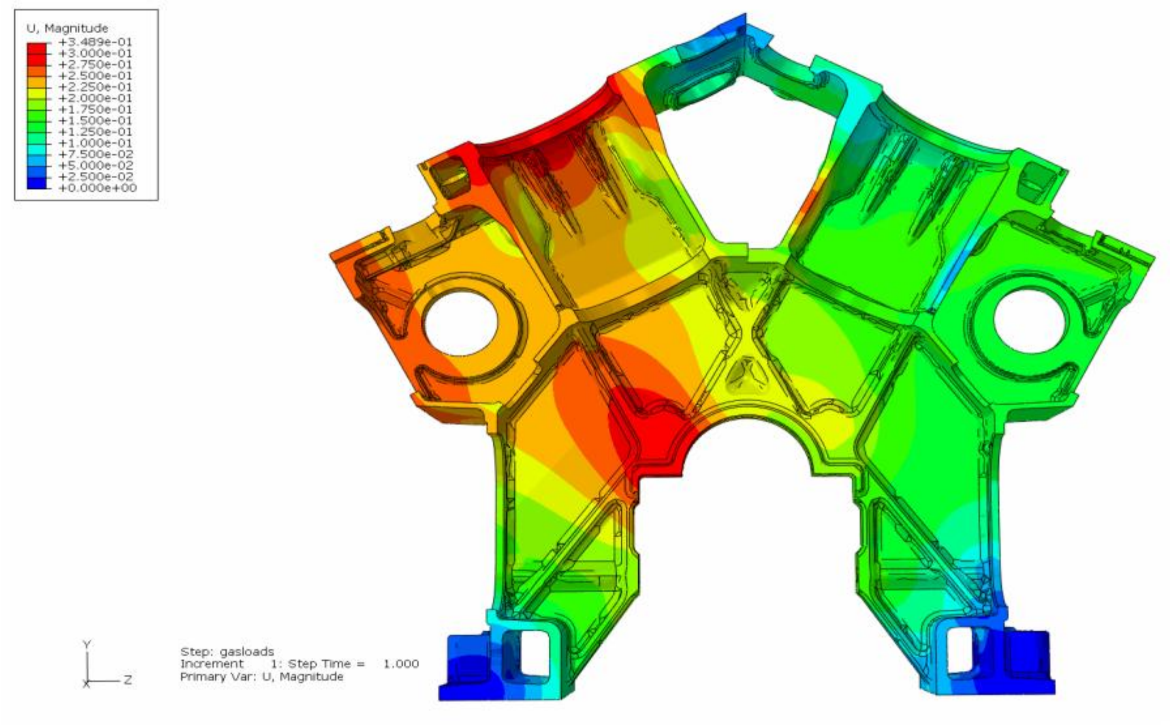


Figure 5. Displacements.

These calculations and FEM pictures could be helpful in the future when Wärtsilä is about to decide to stitch or replace an engine block after a breakdown has occurred.

By comparing the actual damage to FEM pictures, one can decide if the damaged site is at a highly loaded place or a low stress area.

If the damage is located in a low stress area, then could be suitable for metal stitching.

If the damage is located in a high stress area, then it could be good to consider replacing the engine block and by that avoid possible re failure.

2.5 Analysis of strains in cast iron joints

Previous studies of the Metalocking method have been able to determine some interesting and important conclusions. A Master´s thesis made by Andreas Autio and Kristoffer Odnegård at Chalmers University in Sweden has come to the conclusion that the metalock keys made of iron-nickel alloy do not have the same thermal expansion as cast iron but the opposite, very low thermal expansion. This may be even negative in some temperatures, meaning that the keys (locks) will not expand in the same matter as the surrounding material. Furthermore, the thickness of the material from the repaired joint to the first keyhole on the locks is an important parameter when considering the strength of the repair. If the material is too thin, it gets too weak resulting in the fact that the keys in adjacent holes tend to be unable to function as load carrying elements.

Simulations show that the hammering treatment done when installing the keys gives rise to residual strains, primarily at the top of each keyhole in the cast iron material.

A larger distance between keyhole patterns has a beneficial effect on the strain distribution in cast iron. As seen in the picture below, the strain fields seem to be more severe in the upper strain diagram where the keys are closer together.

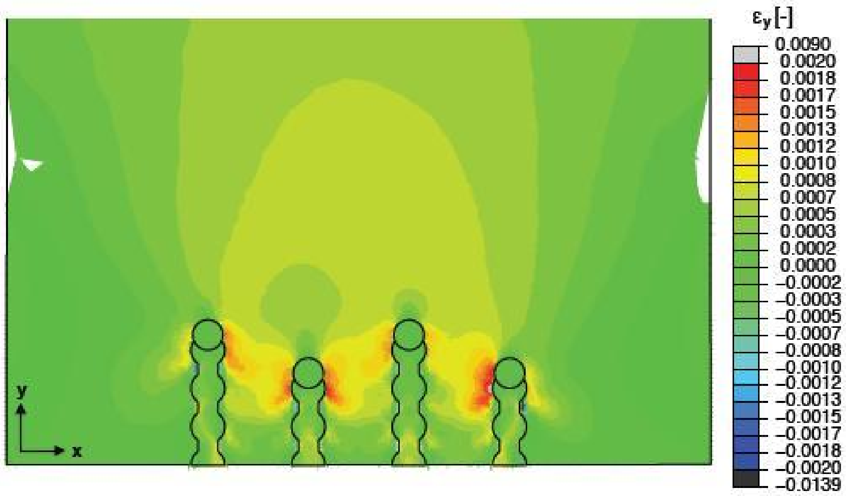


Figure 4.44: Numerically predicted ε_y strain field in a joint with 20 mm distance between the keyholes.

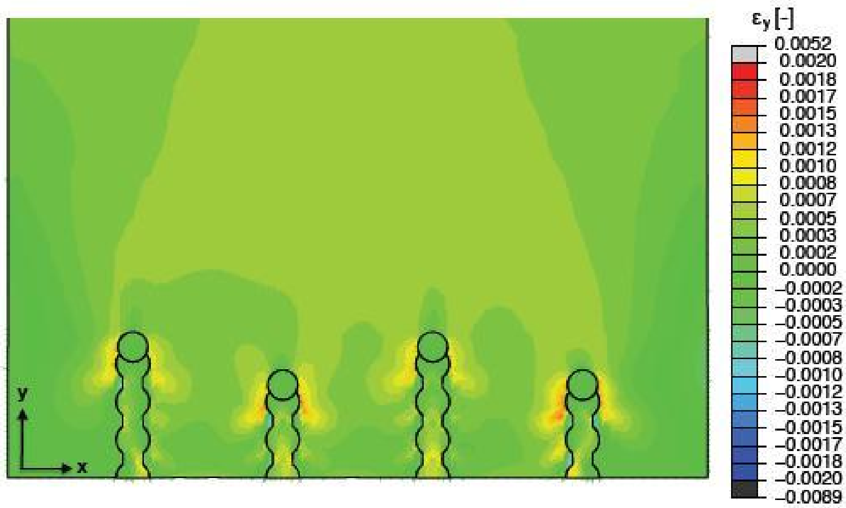


Figure 4.45: Numerically predicted ε_y strain field in a joint with 30 mm distance between the keyholes.

Figure 6. Strains of Metalock keys.

2.6 Metalock

As mentioned in chapter 1.1.1, Metalock is an international association with franchises all over the world. Metalock company offers many kinds of repairs, to many kinds of industries.

The Metalocking method is the oldest of these repairs thereby the name of the company. Several other stitching methods are based on the Metalock method.

The procedure for cast iron repair with Metalock method is as follows:

A drilling guide/jig is positioned across the crack and fastened with a hardened screw in the middle of the crack. Then a hole pattern is drilled with needed spacing and intervals to be able to fit the keys. When the jig is removed, the remaining webs of material between holes are removed by using a pneumatic chisel. The depth of the hole patterns is to be no more than 90% of the material being repaired. Preformed Nickel alloy Metalocks having a slight interference fit to the slot are driven in with a thin-bladed tool until they bottom out, creating a bridge across the cracked parts. The lugs are then peened to lock into the casting. This material is specifically chosen because it is both strong enough to take shear loads and ductile enough to provide the necessary elasticity. The last lock installed sits slightly above the surface of the metal, and is peened to interlock the casting and Metalock key. After fitting the locks, special threads are placed along the entire crack. These pre-stress the keys and prevent the leakage of liquids and gases and stop the movement of the casting. A standard procedure is to install a thread at each end of the crack to minimize further crack growth. After each key is installed, threads are placed on either side of the lock and centered on the crack. Then threads are fitted to any remaining crack between the locks.

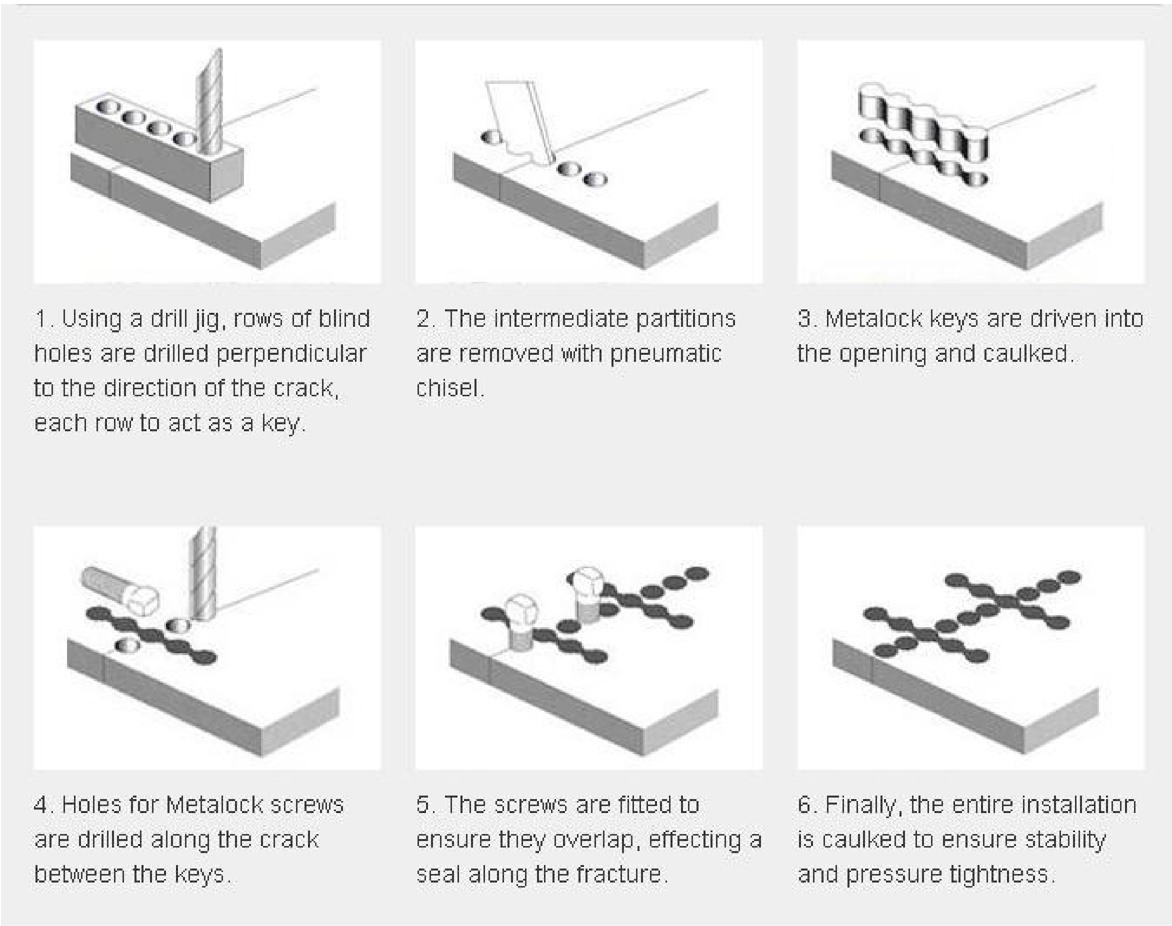


Figure 7. Procedure of Metalocking.

2.7 Lock n Stitch

The company Lock n Stitch performs cold repairs of cast iron. The cold repairs include metal stitching and thread repairs. Metal stitching is done by filling the crack or gap in the casting with screws and securing with locks. There are three main parts in LnS metal stitching, two types of screws, the C series stitching pin and the L series stitching pin and the locks with sizes from L10 to L60.

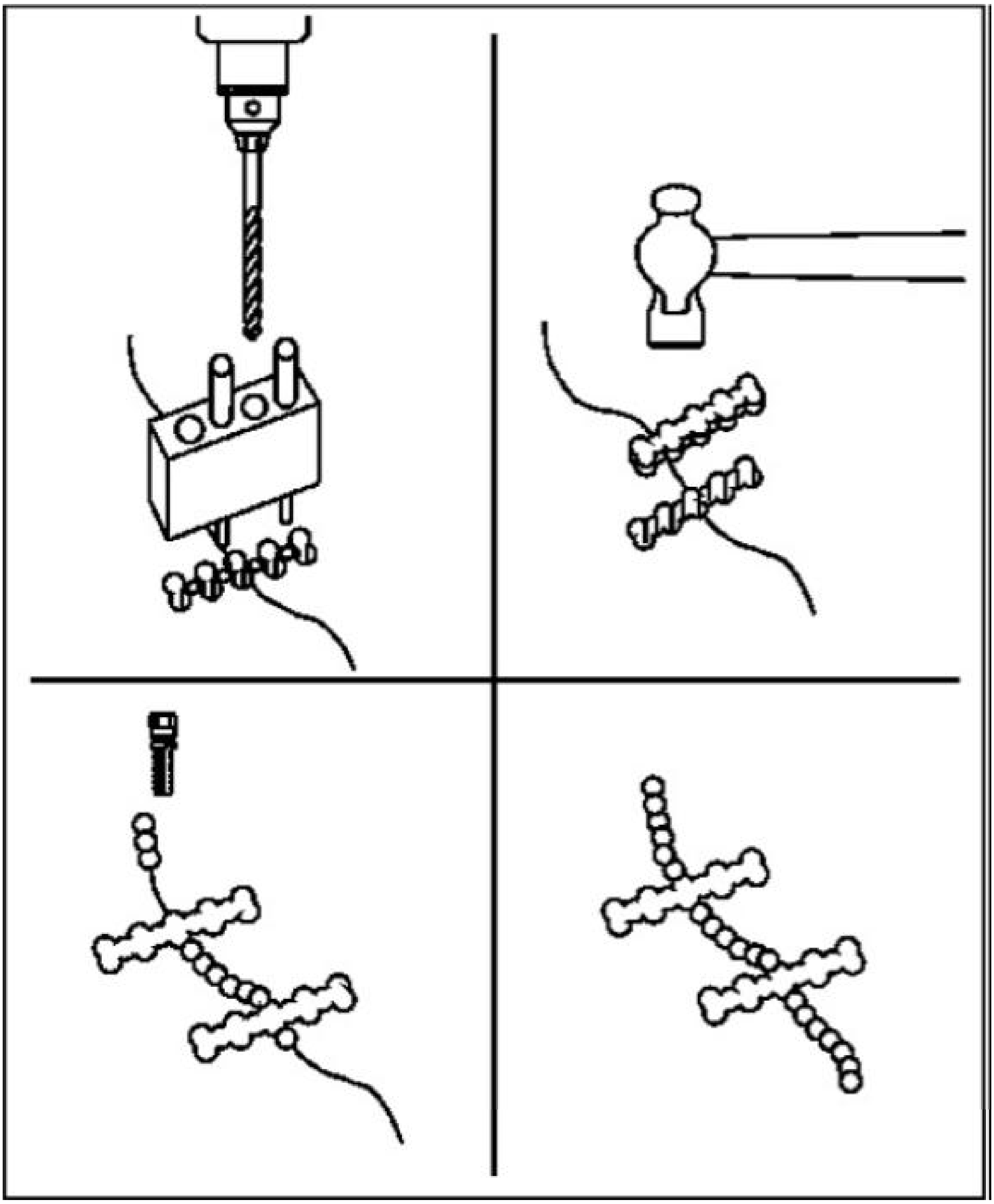


Figure 8. Procedure of LnS

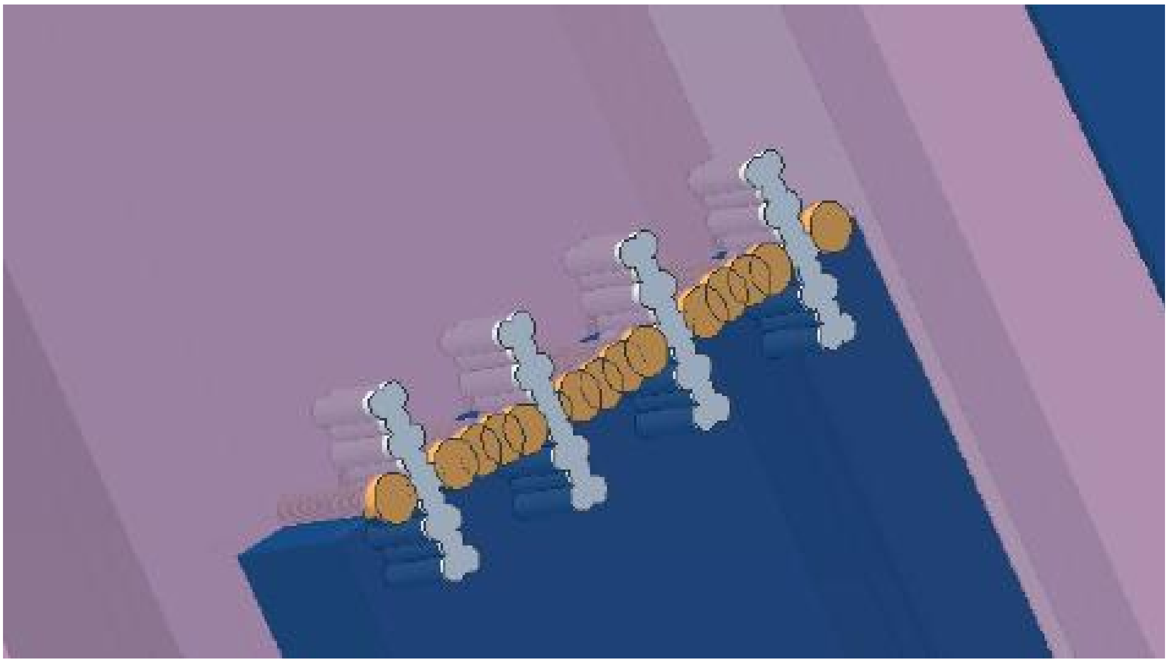


Figure 9. 3D animation of a Lock n Stitch repair.

C locking pin, also called Castmaster, can be made of any material and therefore it can also be suitable for repairing most metals. The shape of the screw is accomlished by CNC manufacturing and it also has a practical function. When tightening a Castmaster screw into a crack where a threaded and countersunk hole has been made, the screw head breaks and leaves only a small part of the screw visible above the crack. The screw head always breaks at a certain moment in force, creating a pulling force towards the middle of the crack, due to the shape of the threads and the contact surface of the remaining part of the screwhead. The castmaster pins are then installed in an overlapping way until the entire crack has been removed and replaced by interconnected stitching pins.

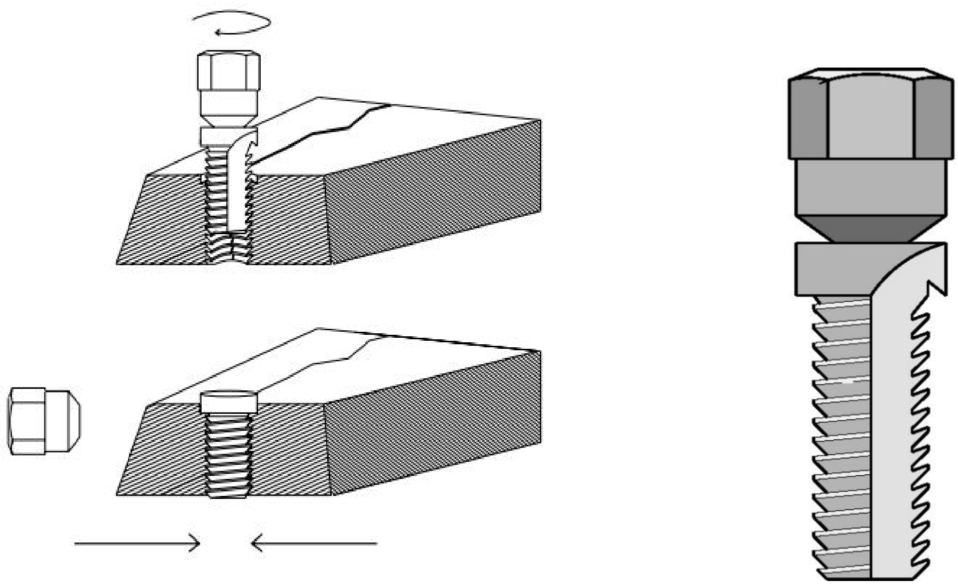


Figure 10. Castmaster stitching pins

L series stitching pin. In some repair cases, spreading is needed instead of pulling. When the L series are tightened into place, they exert a spreading force in the crack. As with the C pins, the brake off groove causes the screw head to break at the same torque every time. It is also possible to install these stitching pins in an overlapping system. The L series pins can also be used if the angle of installation exceeds 20 degrees.

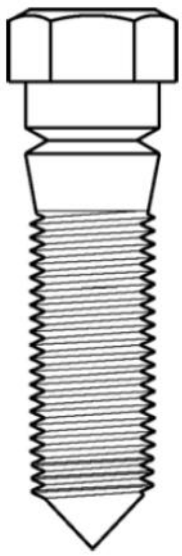


Figure 11. L-series stitching pin.

Locks are used to add strength and stabilization across the crack and to prevent any expansion of the crack. Drill jigs are used to drill hole patterns corresponding to the shape of the lock. Several locks are installed in a laminated way into the drilled holes. The locks are to be applied to a depth of 80% of the material being repaired. Locks will not pull the crack together but prevent it from expanding when pressure and force are applied to the repaired site.

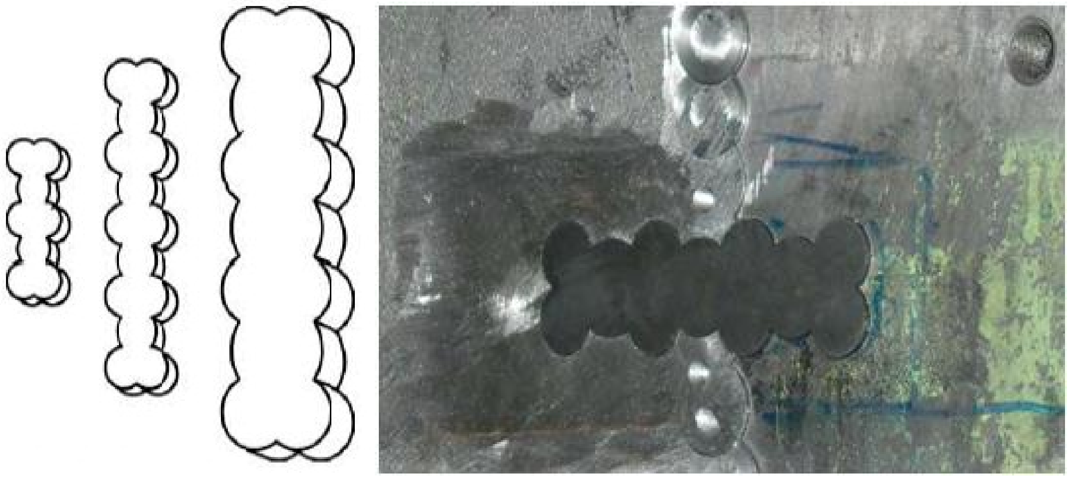


Figure 12. LnS locks.

3 Methodology

This thesis work started with a meeting held in March 2012. Participants at the meeting were my supervisors, me and the commissioners of the work.

At this meeting the guidelines were made for this thesis. The background of the project, the problem to be solved, the description of the project phases, documentation and reporting and the time frames for the project. I have been stationated at Wärtsilä office in Runsor, Vaasa, where I have been doing most of the research.

The following headlines will handle the different phases of the project.

3.1 Feedback research

To be able to get feedback about cases where metal stitching has been implemented in the field on Wärtsilä engines, I had to send out some kind of feedback template, or feedback request. My problem was to who? I started by listing names of people that my supervisors thougth would be stakeholders in this matter. Then I searched the company´s intranet under ”who is who”, where all groups and departments and their participants are listed, and from there I was able to gather a list of stakeholders that most probably had been involved in metal stitching, either on handling projects, warranty or pure service work. Included in this list of stakeholders were also contacts to both Metalock and Lock n Stitch.

Feedback quotation email sent to stakeholders:

Dear Colleagues/Stakeholders

For the evaluation of risks, requirements and results of reconditioning engine blocks with **metal stitching** method, **Technical Service WFI** has initiated a technical analysis of the repair method.

To be able to achieve a reliable and helpful result, we need more cases of experience.

We kindly request you that have information and feedback about cases, or any other knowledge about metal stitching to reply them to me.

Very best regards

Niklas Eurs

Technical Service W32

Wärtsilä Finland, Vaasa

And several cases of experience, with reports of performed service work, were replied to me. I was able to make a list of interesting cases that would be closer investigated.

These cases have also been categorized in severity so that it would be more helpful during researching. In this way it is easy to compare similar damages on different engines to the results of the repairs.

Seven cases were chosen for closer follow-up. These cases were chosen based on the site of the damage, severity or places where leakage is a possibility. Account managers for these installations were contacted and asked to reply with information on how well the repair has been working, signs of cracks, leakages or other problems.

3.2 Field follow-up

A part of this thesis work was also to do a couple of field follow-ups on installations where metal stitching had been performed after breakdown. A golden opportunity came along during summer 2012, when the cruise ship Celebrity Eclipse was harboring Helsinki on a day trip for the passengers. Celebrity Eclipse suffered from breakdown in December 2011. A connecting rod broke and came loose, which also caused the counterweight to loosen and damages to the engine block in several areas were the result of all this. The damages were walls between cylinders, strengthening ribs, cylinder liner guidance bores, crankcase inspection doors, cambox walls and other small dents and cracks.

Technical service W46 contacted me and asked if I would like to join them when they were going to perform a follow-up inspection of the repaired engine block at Celebrity Eclipse. On 31 May I was onboard the ship in company with colleagues from TS W46. A visual inspection was done to all repaired areas on the engine block, and no abnormalities were found during the inspection. The repair seemed to be performed in a professional way and the result looked very promising.

Below are some pictures from the inspection.

Figure 13. *Repaired wall between A1 and A2*

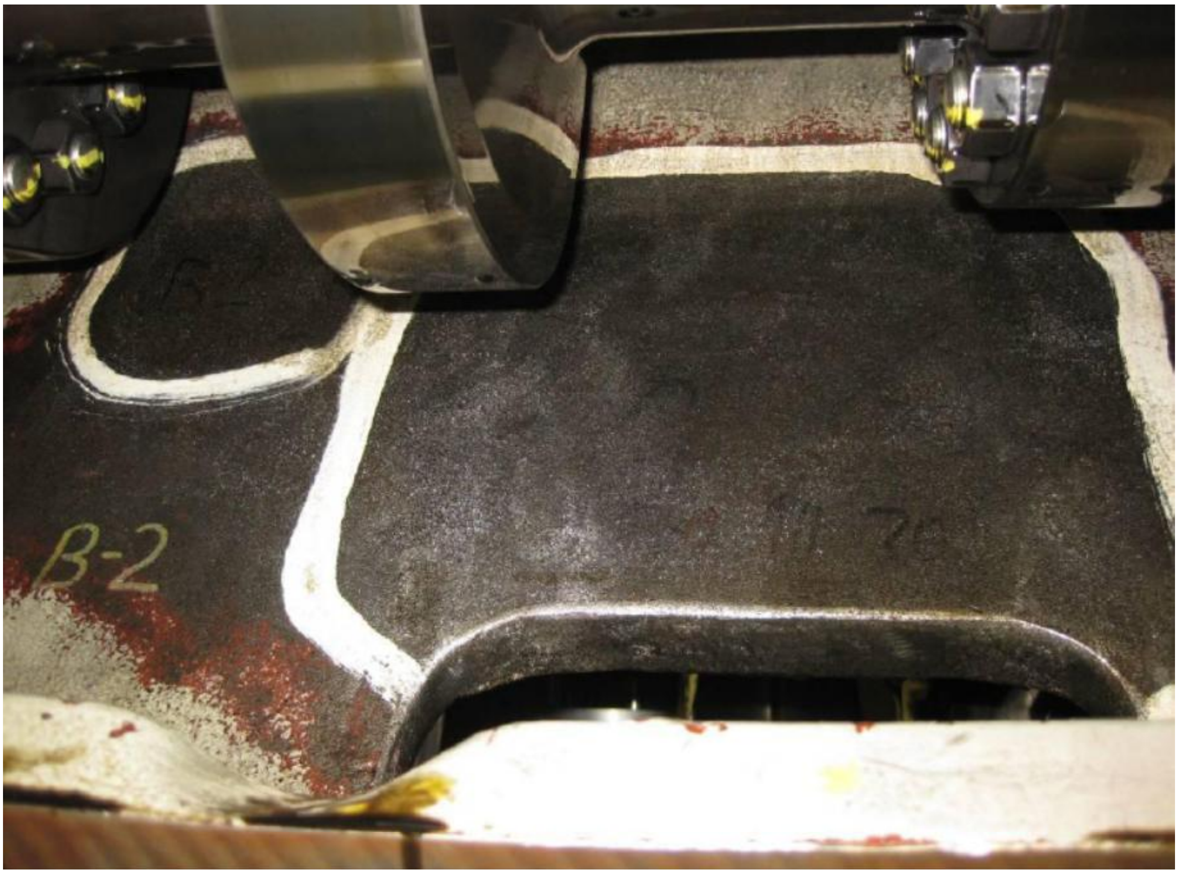


Figure 14. New parts stitched in place in cambox.

3.3 Planning of practical test

At the beginning of the project the intention was also to perform a practical test of the metal stitching. On 7 September 2012 we had a meeting with the R&D department to discuss what kind of tests we were going to perform. At that meeting it was decided that a couple of different tensile tests and a dynamic test of the strength of stitched cast iron parts would be suitable. Parts that would be stitched would be cut out from W20 main bearing caps, which have similar material properties as an engine block, and stitched by trained personnel. A couple of companies and organizations were named as possible performers of the actual tests.

I then purchased a couple of un-machined main bearing caps from the company supplying Wärtsilä.

I calculated the approximated force needed for performing the tests and specifications about the tests and sent out a request to concerned companies and instances.

After receiving feedback from the companies that would perform the tests I realized that I would need bigger testing pieces to be able to fit their testing equipment. Luckily I found some scrapped Vasa 32 main bearing caps to cut my test pieces from.

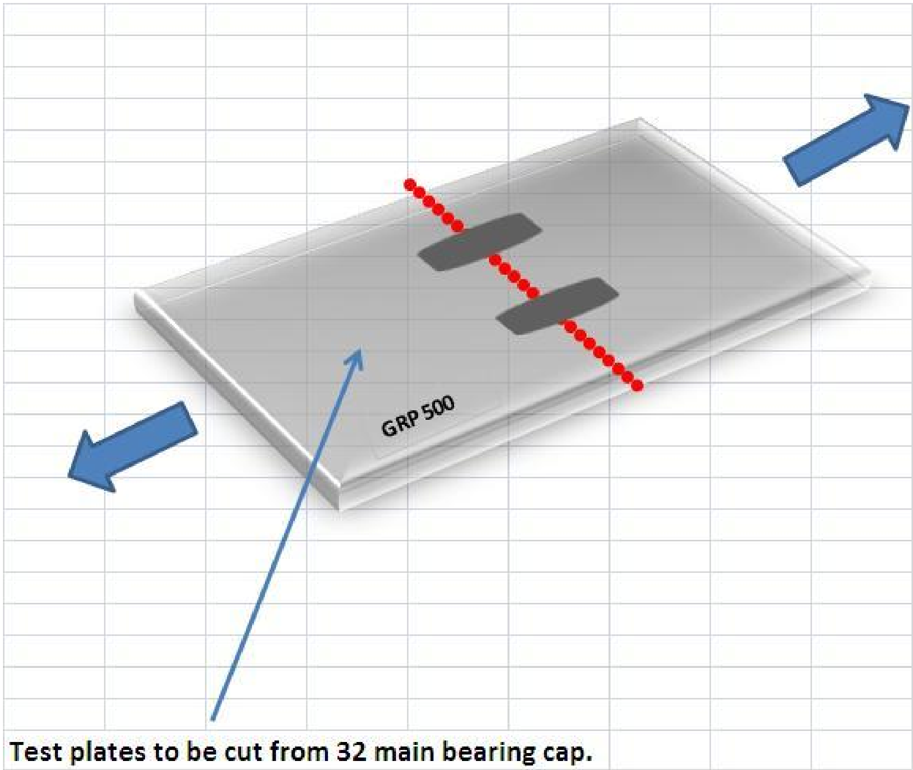


Figure 15. Approximated shape of tensile test part.

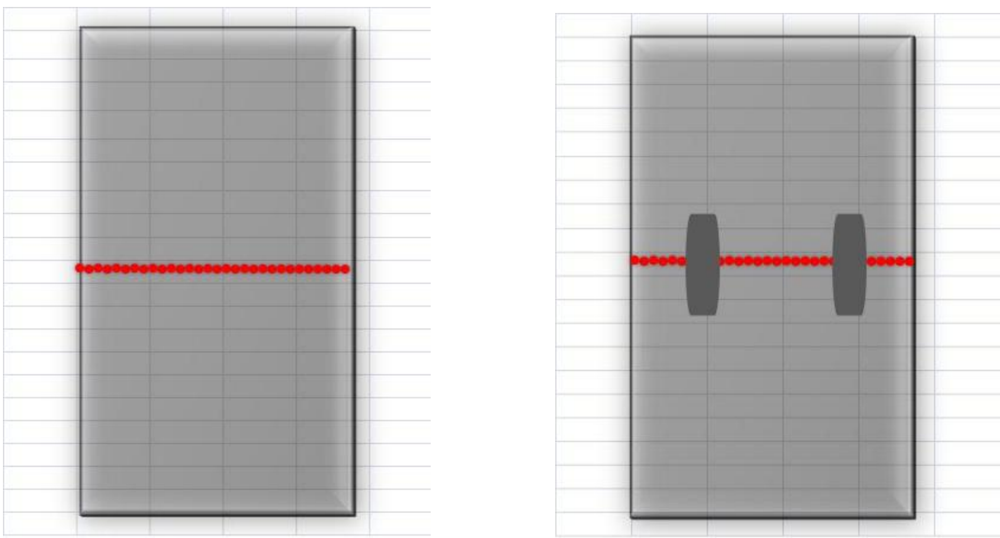


Figure 16. Couple of stitched plates to be tensile tested

3.4 Performing of practical test

All in all 16 test plates were cut out from Vasa 32 main bearing caps and machined to 250*60*12mm. The material is GRP500, and the calculated tensile strength for a piece of this material and size would be approximately 360 000 N. The plates were cut into two pieces and sent to Lock and Stitch in Turlock, California. LnS stitched the test plates I prepared. After receiving the test plates back to Finland two of the test plates were crack tested with magnaflux both for better visibility of the repair and to see if any cracks could have been propagated already during the performing of the repair. One small shallow crack was found on test plate no.16, nothing severe. After this 11 of the 16 test parts were sent to Metlab in Tampere for tensile testing. The remaining 5 will be used for dynamic testing of the repaired joint later on when the tensile strength is known.

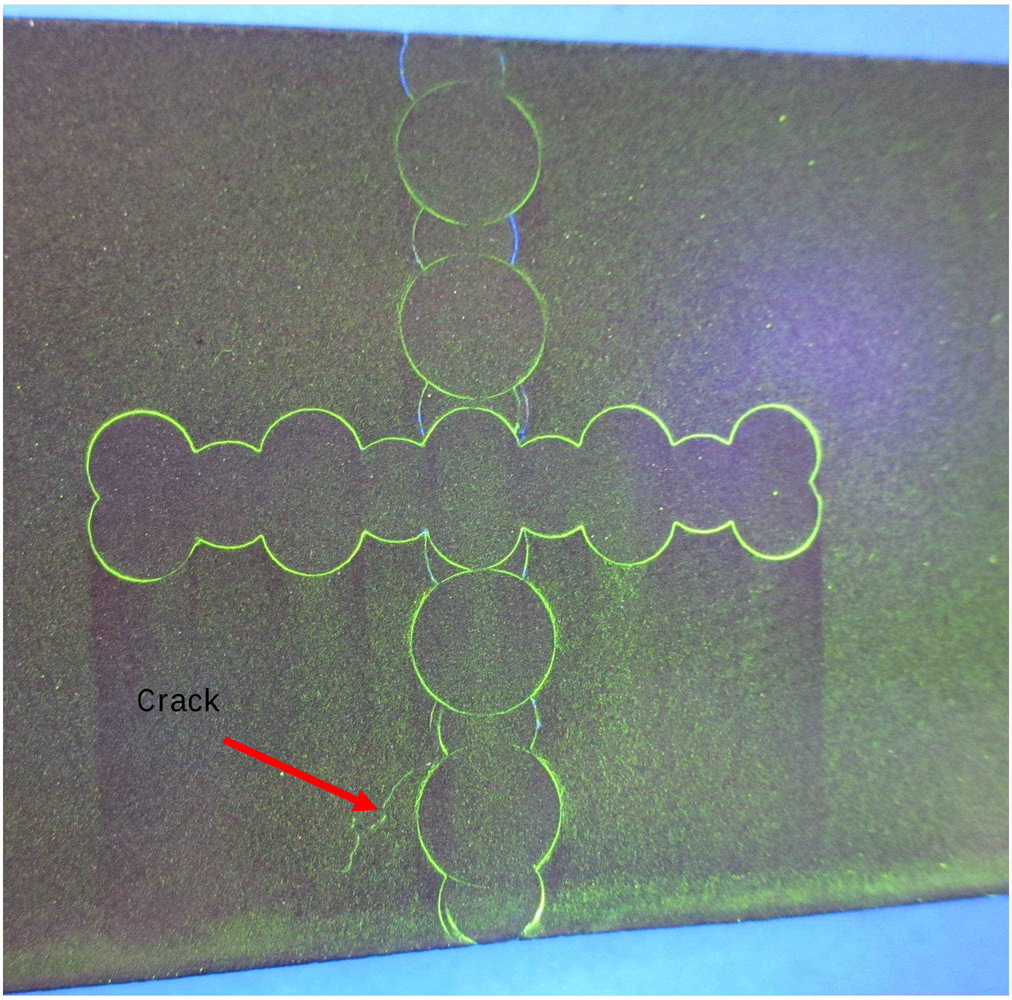


Figure 17. MagnaFlux crack testing.

3.5 Classification societies

An important aspect in this project is class approval of the metal stitching. All ships in use are class approved by some of the classification societies. When changes and services are made to the ship, classification societies have to approve the changes for the ship to be able to operate under insurance and safe conditions.

I have contacted four of these classification societies to hear their points of view of this kind of repairs. It is very important to know classification societies guidelines in this matter, because without their approval a vessel can´t be put back in service.

Both Metalock and Lock and Stitch have as companies been approved, by at least Lloyds Register, to repair components with their repair methods. However, this approval does not give them the rights to repair any object, the repair must be undertaken a written procedure and accepted by the attending surveyor present at repair site. These approval letters can be seen as appendices.

Below are some comments from experts working for the classification societies.

3.5.1 ABS

After several attempts both at the ABS main office in Finland and at global ABS contacts, I have not been able to get ABS to give their statements concerning this matter. I don´t know if they are so busy that they can´t handle it, or if they just don´t care. Anyhow the result for me as a customer is the same: no response.

3.5.2 Lloyd´s register

”Metal stitching is a repair technique which has been accepted by Loyd's Register. We have approved a number of Metalock International Association member companies for the application of the process, but in addition each repair is assessed on a case by case basis.

The repairs have to be undertaken to a written procedure that is specific to the component being repaired and been reviewed and accepted by Lloyd's Register prior to commencement of the repair. The repair itself has to be undertaken with the Lloyd's Register surveyor in attendance.

Repairs by metal stitching are recognized as temporary repairs. However, if the repair has completed two years satisfactory service it may be recognized as a permanent repair.”

Colin Waylen
Principal Specialist
Lloyd's Register

3.5.3 DNV

“We accept repair with stitching on engine blocks in low stress areas, and where there is no risk of leaks (occasionally also when we consider that the risk of leaks can be adequately controlled), for ships in operation. Experience is generally good.

We have no particular requirements in this respect, and we do not certify the sticks, nor the companies doing the repair.”

How do you determine if damaged area is low or high stress area?

”Different from case to case: Usually, engine builder can provide the best info. Else, general engineering evaluation is used. Only very rarely we base it on own calculations in DNV. Regarding loads in different places of the engines, stress levels lower than 50 % of the maximum allowed stress level (according to class rules / criteria) is usually considered as “low stresses”.”

John Olav Nøkleby
Machinery
DNV Høvik

3.5.4 Germanisher Lloyds

”We often deal with repairs by Metalock / Lock n Stitch. At GL classified vessels each of this kind of repair procedure will have to be approved individually by our Society.

For repairs there do not exist any special Rules at GL - besides of general demands e.g. that stamped parts must be replaced by stamped ones.

The above named method is a pure repair technique - it will never be used for connecting e.g. two parts during new buildings' constructions.

All approvals are based on unique decisions - often found in cooperation with the repair company who carries out the works and the engine manufacturer. In some cases there will be taken results of finite elements method for assessment. For repairs in way of accelerating force loaded areas this method is not applicable according to our experience. Our policy is it to acknowledge such repairs always as to be temporarily for the time being.

A satisfactory re-survey / crack test of he repaired area after a certain operating time (e.g. 3000 running hours) enables us to accept the repair as permanent.

Almost 100% of all repairs carried out by this method were successful.”

Ingmar Poetzsch
Marine Engineer/ Machinery Expert
Germanischer Lloyd SE

4 Results

4.1 Collected repair cases

Lock´n Stitch repairs			
on Wärtsilä engines	Follow-up		
Installation	Engine type	Product no.	Additional information
Allure of the Seas	W16V46		Cylinder liner lower guidance and cam box.
Carnival Magic	W12V46		Cylinder liner lower guidance and cam box.
Puerto Plata CEPP	18V32		Petris report
Gaslog Singapore	W12V50DF		Broken HT-water channel
Nejapa	18V32		Cylinder liner upper and lower guidance.
Oceania Regatta	12V32		Cylinder liner lower guidance.
Sea Dream			Inspection hatch.
Sea Escape	8R32		Zeisured piston…
Statendam	8 ZAL 40S		Big part from engine block loose.
Soyapango	W18V32	5039	Cam box damage.
Celebrity Eclipse	W12V46	PAAE072245	Loose counterweight, many dents and holes in engine block.
Deepwater Pathfinder	18V32		Lower liner bore, cambox, and other dents and cracks.

Table 1. Lock n Stitch repair cases

Metalock repairs			
on Wärtsilä engines	Follow-up		
Installation	Engine type	Product no.	Additional information
M/V Kristina Regina	12V22MD-C	4270	Cylinder liner lower guidance
Azura	W12V46	PAAE091873	Charge air cooler housing
Captain FPSO	18V32	6964	?
Iberafrica	18V32	20518	Camshaft bore
Centrale BL1	W18V32	22353	Cylinder liner lower guidance
Carnival Dream	12V46	PAAE059487	Crack in crankcase hatch
Nippon Steel	18V32		Cylinder liner lower guidance
British Laurel	4L20		Gear wheel trough inspection door
Besos	W28SG		Erik Jungner tipsade om detta case.
Egasa	12ZV40/48		Cylinder liner lower guidance
Evinco			Lower liner bore
CPT Lungtan			Lower liner bore and cambox
Khulna power	18V32		Gear wheel bearing housing

Table 2. Metalock repair cases

4.2 Results from collected repairs cases

It was decided that a follow-up would be done for some installations where the damage could be considered as more severe. The installations found below have all suffered from severe damage to the engine block and have been repaired by metal stitching. Some interesting factors are leakages, running hours since finished repair, cracks or visible abnormalities with the repair and other problems related to the repair.

Statendam

This engine suffered from a major breakdown where loosened engine parts caused a large piece of the engine block to crack and come loose. Also a cylinder liner lower bore was damaged as well as other smaller dents and cracks. The repair was done by LnS.

Repair: The engine block was repaired by stitching in a new cast piece fitting the hole.

Figure 18. Repair of Statendam engine.

Follow-up:

Roughly 5000 running hours since repair, no leakages, no problems reported. The only problem they had was that Lloyds Register was initially reluctant to approve the repair. But after some pressure from HAL, Lloyds Register approved the repair. The customer is very satisfied with the result.

Nippon Steel

The Vasa 18V32E engine at Nippon Steel had a breakdown in 2011 and Metalock repaired the damaged areas in February 2012. The damages were cylinder liner lower bore and some other small cracks. New pieces were manufactured and stitched into place. After finished stitching and locking, the damaged area was grinded, painted and pressure tested.

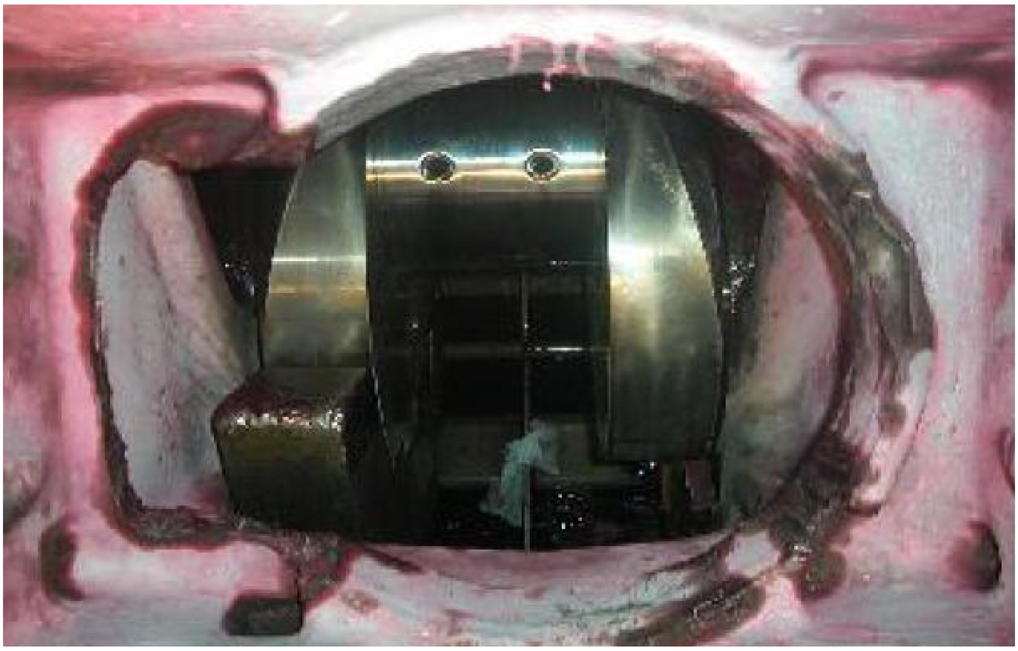


Figure 19. Crack testing of damaged area.

Figure 20. New manufactured piece.

Figure 21. New piece metalocked into place.

Figure 22. Job finished and ready for pressure testing.

Follow-up: The first follow-up inspection was done in July 2012 when the engine had run 800 hours. The engine block was crack- and pressure tested and no abnormalities were found.

The engine has now (25.10.2012) run 2000+ hours and no reported problems.

British Laurel

The 4L20 engine on the ferry British Laurel suffered from a engine block damage in 2008 due to a loosened gear wheel. The damage was not that severe, but located in an unusual site on the engine block. Most damages to the engine block occur due to connecting rod or counterweight failure, thus the damages are often located in that area. In this case unneeded material was grinded away and a new piece was fitted with keys and metalace screws.

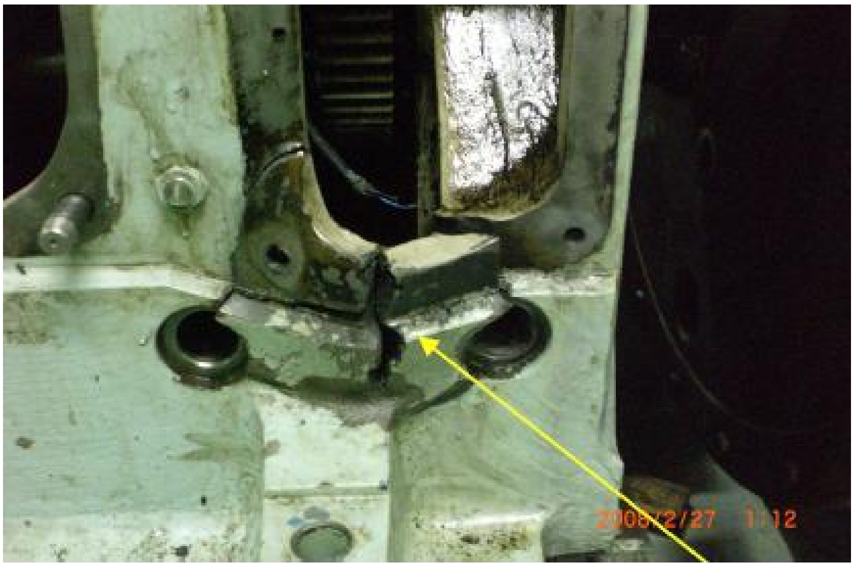
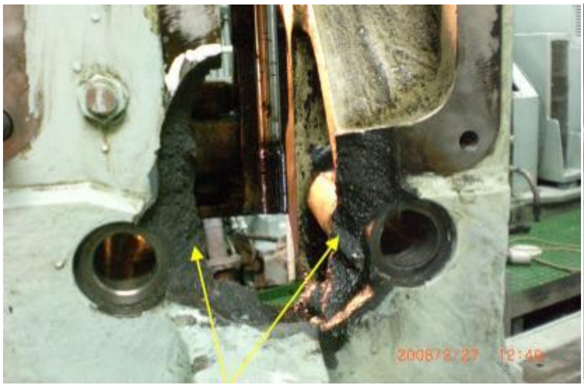


Figure 23. Damaged area.

Figure 24. Loosened gear wheel.



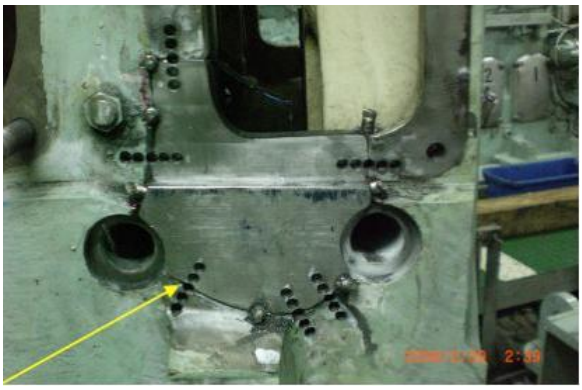


Figure 25. Cracked parts removed

Figure 26. New piece fitted.

Figure 27. New part locked with keys and metalace.

Figure 28. Finished result.

Follow-up: The running hours of No.3 Generator when the metal stitching job carried out was 18278 Hrs. Present running hours of No.3 generator is 34959 Hrs. Total running hours after metal stitching job carried out is 16681 Hrs. No leak has been observed from the place where metal stitching is carried out, no other problem faced about metal stitching till date." Quoted by British Laurel chief engineer on 9 November 2012.

CEPP Puerto Plata

In May 2011 the W18V32 engine in Puerto Plata power plant broke down. During this breakdown the engine block and crankshaft were badly damaged. The engine block was repaired by Lock n Stitch and put back in service in November 2011. After this service the engine operated for roughly a week before the repaired area started to leak. This is an interesting case, because it is the only case I heard of where the repair done by LnS has not been able to withstand the forces and failed.

After the leakage the engine block was repaired again in late November 2011. Also this time, after a week in operation the leakage occurred again.

The third repair was performed in February 2012, and once again the engine block started to leak cooling water after one week of operation.

After the fourth repair the engine suffered from another breakdown, which was thus not related to the repair done by LnS, but due to poor service work during overhaul.

A service engineer was requested to visit the site and Mr. Petri Lautamäki, from TS-W32, travelled to the installation to investigate the cause of the second breakdown.

Below are some pictures from the first breakdown.

Figure 29. Large piece of the engine block missing.

Figure 30. A new cast piece is fitted into place and stitched together with the engine block.

Figure 31. Stitching with pins done.

There were also other areas of the engine block that were damaged, such as the cylinder liner guiding surfaces and the walls between the cambox and the cylinder etc. However, this repair seen in the picture above is the one causing the problems with leakages. As visible in this picture, the upper cylinder head bolts on the damaged cylinder, were removed and at the same time the large piece came loose from the block. This led to the fact that the new cylinder head bolts were machined into the new piece stitched into place.

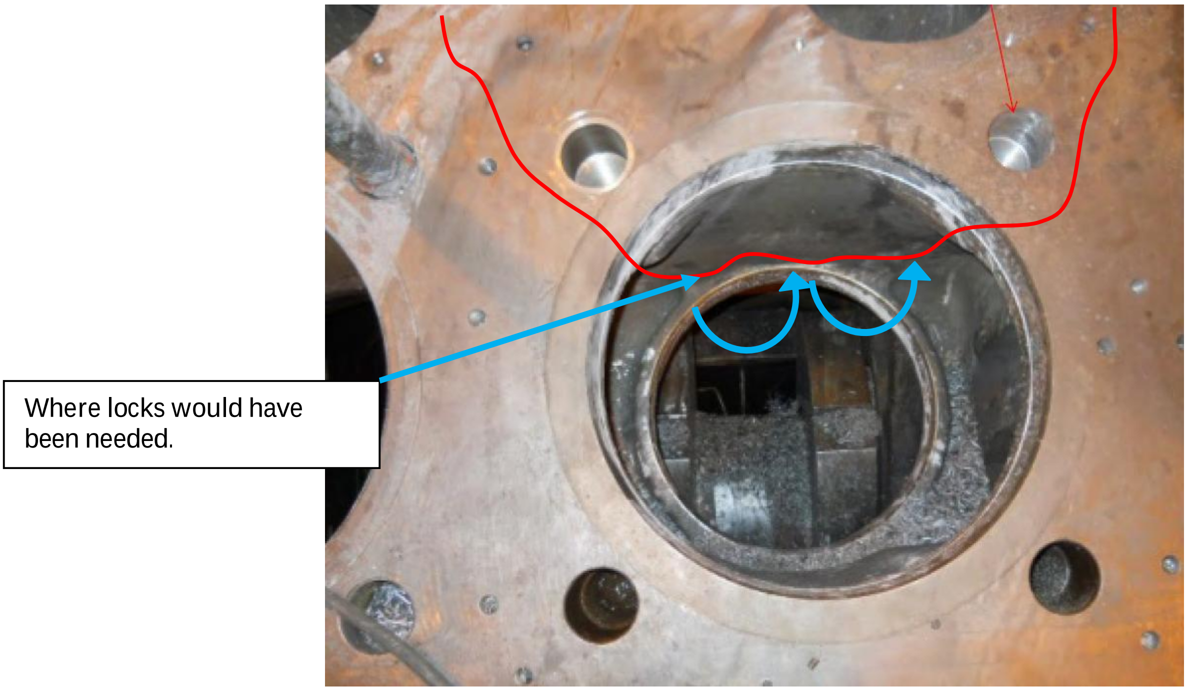


Figure 32.

New threaded holes made for the cylinder head bolts.

Below the damaged area can be seen:

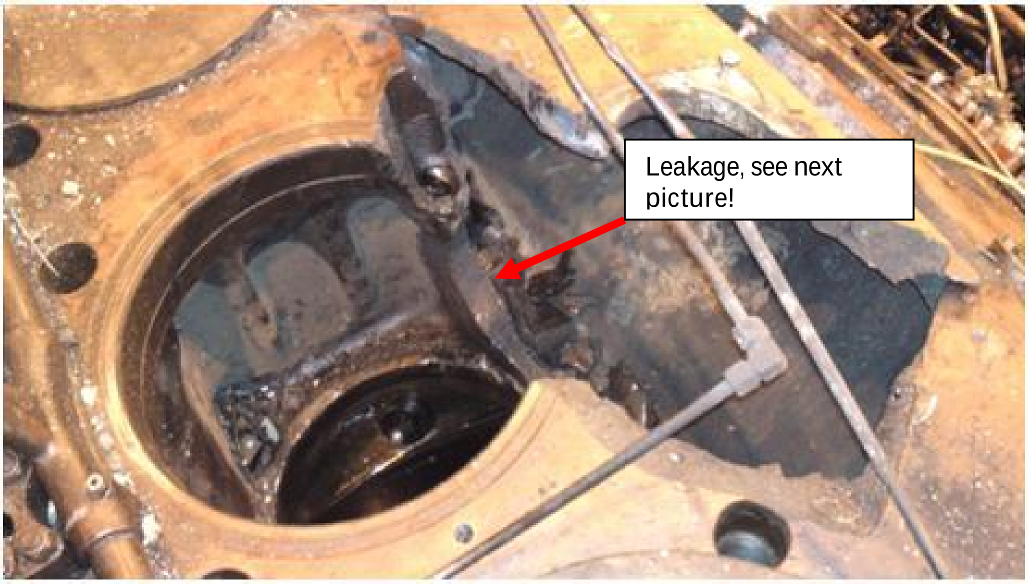


Figure 33.

Because the cylinder head bolts are within the repaired area, the repair will be exposed to high loads due to firing pressure from the cylinder. This means that during firing pressure you will get a great lifting force on the new piece stitched into place.

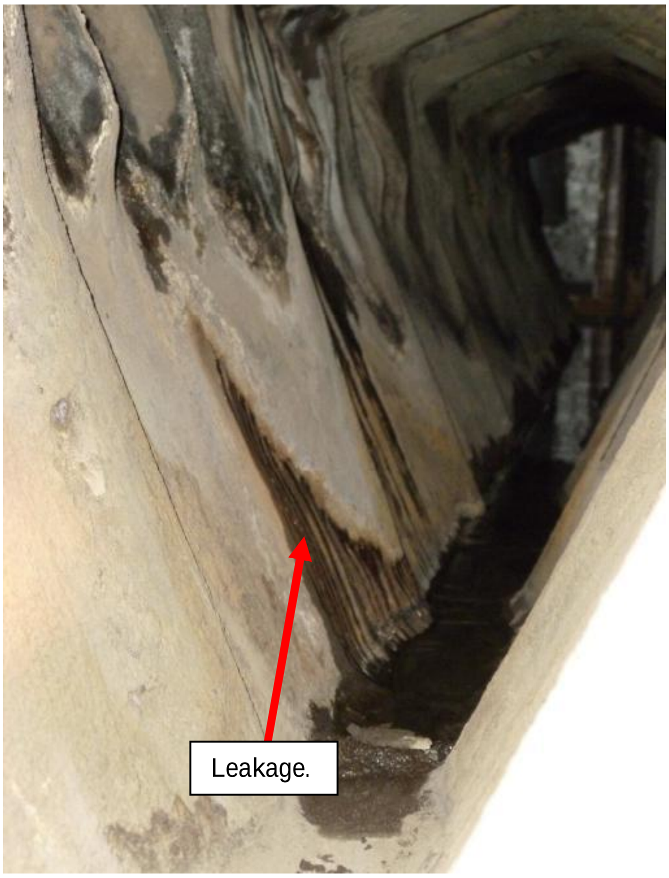


Figure 34. Leaking repair.

During Mr. Petri Lautamäkis investigation it was cleared that there were no locks installed on either side of the repair in vertical direction, meaning that forces from firing pressure were led to the new part stitched into place. And due to the lack of locks, the stitching pins had to take most of the forces, which they obviously did not cope with. The reason for the absence of locks is probably that installing locks must be done on a flat surface.

The conclusion of Mr. Lautamäki´s investigation:

- Engine block is damaged during the breakdown.
- Several repairs have been carried out after the major repair and every time the block was leaking.
- The reason for the damage is failed connecting rod upper part .
- The block repair machining is done in very strange order and the replacement piece is on the highly loaded area.
- Most probably the repair cannot handle the dynamic load from the firing process.
- Wärtsilä have come to the conclusion that the engine cannot be operated safely.
- The whole engine is recommended to be replaced.

- Some of the inspected parts are not supplied by Wärtsilä.
- Several pirate parts are used.
- Original spare parts are recommended to be use.

Nejapa

In 2004 the diesel generator #9 at Nejapa Power suffered from damage to the engine block, due to a broken connecting rod. The lower and upper landing surfaces for the cylinder liner were damaged and also two holes in the cylinder liner cooling water space were results of the breakdown. One of the holes was located 12 o´clock through the wall into the receiver and the other 6 o´clock through the wall towards the camshaft. The repair was performed by LnS. New patches were manufactured and stitched into place in the holes, and the landing surfaces were machined to oversize and sleeved.

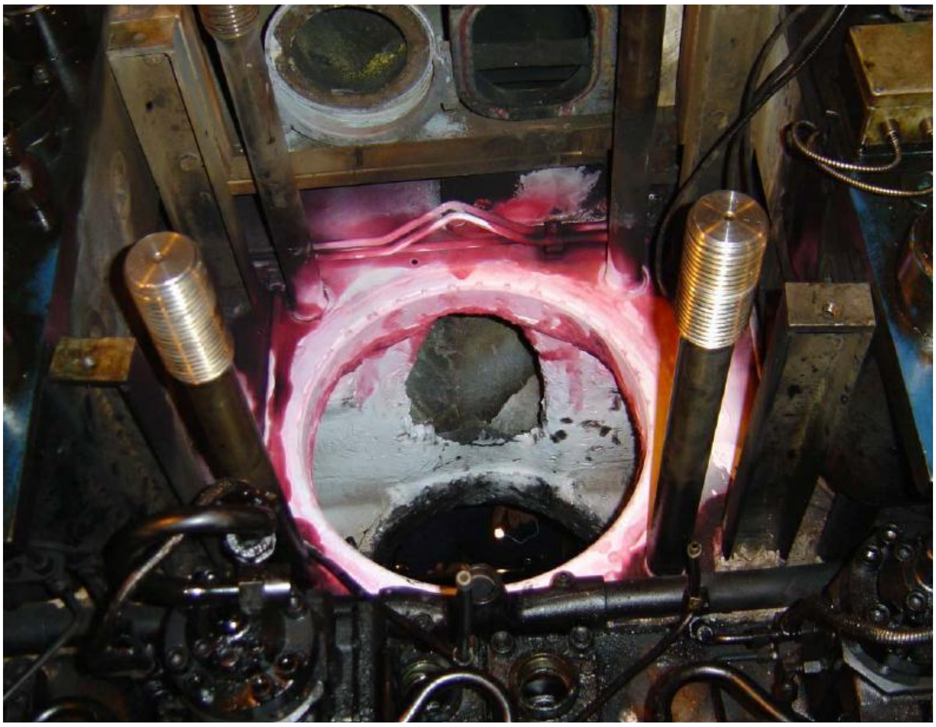


Figure 35. Crack testing at damaged site.

Figure 36. New patch stitched fitted.

Figure 37. Finished result.

Follow-up: The service manager working at site said that there have been no leakages and no other problems with the repair. The engine has run +30600 hours since repair date. The service manager also said that they had recently done another repair by stitching, this one located around inspection doors. Also this repair has been working without problems for +2700 running hours.

Khulna Power Company

In 2004 the 18V32 at Khulna Power Company had a failure of the fastening screws for the extension piece for intermediate gear. This resulted in a lack of lubrication and bearing seizure. The seizure also affected the bearing housing in the engine block, which had to be machined to oversize for receive an adapter. During this machining mistakes were made and the result was a hole trough the wall into the waterspace around the cylinder liner. The hole was repaired by Ciserv using the metalocking method and steel putty.

Figure 38. Metalocking of waterspace.

Follow-up: Quoating Plant manager Acharjya Sreenath:

”The metalock repair is definitely not as original but it has been serving the purpose well. We check fastening of the installed housing adapter i.e., tightness of the adapter screws and also the metal stitching in the water jacket side periodically. Once we experienced slight water leakage through the stitched area and fixed it by putting steel putty. The recent engine running hour is 72864 as on 19.11.2012 and the failure occurred at 16281h.”

Oceania Regatta

In 2011 the Vasa 12V32 onboard Regatta was repaired by LnS after having suffered from a breakdown that damaged the engine block. Cylinder liner lower bore, a crack into the cooling water channel, inspection door damages and other small cracks and dents were the results of the breakdown.

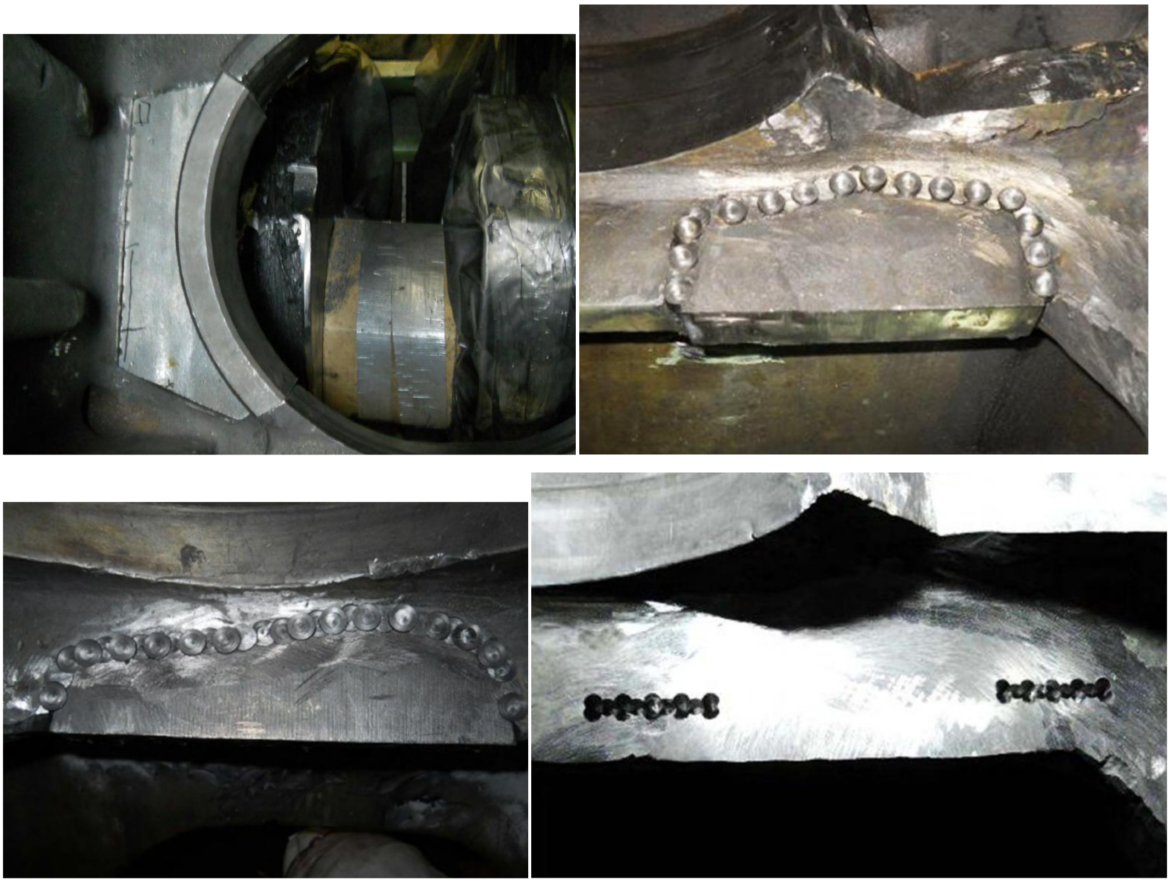


Figure 39. Stitching on 12V32 on Regtta.

Figure 40. Damages with new patches stitched into place.

Follow-up: No leakages or problems reported. The engine has run 58 300 hours since the repair without problems.

Gaslog Singapore

In December 2011 Gaslog Singapore had a breakdown on cylinders A1 and B1, the reason for this was a loosened big end bearing housing. The result of this was damages to the oilsump, crankcase, cylinder liner lower bore, inspection doors and also HT-water channel.

Figure 41. Damaged HT-water channel.

The engine block was repaired by Lock n Stitch, by stitching and machining.

Follow-up: The engine has run 1638 hours after repair in December 2012, and no leakages or problems have occurred. Next follow-up will be done at 6000 running hours.

4.3 Results of tensile test

The tensile tests were carried out with universal testing machine. A specimen cross sectional area from Lock and Stitch area was measured before testing and these dimensions were used for strength calculations. The maximum forces during test and breakage location were recorded. The results of the tensile tests are confidential and will be presented only within the company of Wärtsilä.

4.4 Results of fatigue test

Due to lack of time, the fatigue test will be performed later on. More info in chapter **6, Discussion.**

4.5 Classification societies´ guidelines

A common demand for all classification societies is that when repairing an engine block by metal stitching, these repairs are approved case by case, often with a class society surveyor present at site. However, the demands differ slightly between the societies.

Lloyds register

- Case by case approval.
- Requests a written procedure of scoped service work before approving start of repair.
- LR Surveyor present at site.
- Refer to metal stitching as temporary, however after two years of satisfactory working repair it can be classed as permanent.

DNV

- Case by case.
- Approving repair in low stress areas where there are no risks of leaks.
- Low stress areas on engine block are recognised as where levels lower than 50 % of the maximum allowed stress level according to class rules and criteria.

Germanischer Lloyd

- Case by case.
- Stamped parts to be replaced by stamped parts.
- Only for repair, not for constructing.
- In some cases the Finite analysis is used.

- Repairs in accelerated force loaded areas are not to be recommended and these types of repairs are always seen as temporary.
- Follow up inspection with crack testing after some time in operation i.e. 3000 running hours, after this recognized as permanent repair.

Through mail correspondence I have taken part in discussions where Lock n Stitch and classification societies have been discussing a classification of their repair method. The CEO of LnS, Mr Gary Reed, has made a suggestion of levels of approval for their repair. This summary is based on three levels of approval. This also includes their thread repair service, Full torque.

Three levels of Approval.

Gary Reed has suggested to Classification societies **three levels of approval status** that can be considered for any potential LNS metal stitching and FT bolt hole repair. One could be assigned by the inspector to meet the short and long term needs of the shipowner while following responsible and reasonable guidelines.

Permanent Status

Any simple repair whose cause is known and can be prevented in the future.

a. Cracked bolt holes
b. Freeze cracks
c. Cracks caused by accidents or incidents
d. Repairs with documented long term success

Conditional Status

Any potential repair that does not fall into the limitations of the Short Term repairs below and could be converted to Permanent Status after a specified time period.

a. These repairs would be closely monitored over a prescribed time frame for leaks and or crack propagation.

b. They would include structural damage to engine blocks, blow out holes, cracked cylinder heads, cracked turbocharger housings, etc.

c. After a predetermined time period if the repair shows no signs of leaking, cracking or separating, it could be converted to Permanent Status.

Short Term Status

Any potential repair that cannot restore the damaged part to Permanent Status of repair due to such things as;

a. Manufacturers design issues that cannot be overcome.

b. Previous failed repair attempts by welding on cast iron.

c. Lack of accessibility.

d. Corroded or eroded wall thickness to a point where there is not enough metal to work with.

e. Any other issue that would prevent returning the damaged area to original strength or seal.

These three status levels can simplify an approval process while adding a structured methodology of determining repair feasibility and safety.

In my opinion this is also a very good guideline for the evaluation of whether to repair or not.

5 Conclusions

5.1 Conclusion based on repair cases

Based on the information from the seven different cases I followed up, the conclusion is rather clear. In low stress areas, such as cylinder liner lower bore (also with water space), cambox walls, cracks and dents in crankcase space such as stiffening ribs and partition walls between adjecent crankcases, around inspection doors and side of the engine block overall, the metal stitching method is a very suitable repair method. No repair has come to my knowledge, done in a low stress area, where the metal stitching repair failed.

However, in some areas of the engine block, metal stitching may not be suitable. Sites on the engine block with highly accelerated forces, e.g. around cylinder head fastening bolts and other places directly affected by the firing pressure, should at least not be seen as permanent repairs. This conclusion is very much demonstrated in the repair case CEPP Puerto Plata.

From an economic perspective metal stitching can save the engine owner a lot of money. To give an example, a ship with 4 pieces of W16V32 main engines suffers from a breakdown due to a bent connecting rod from water stroke. The connecting rod breaks and before the engine is stopped the remaining part of the connecting rod stamps a hole into the cambox, crushes the cylinder liner and at the same time removes a piece from the cylinder liner lower guidance bore.

These damages are often the result of a broken connecting rod. Imagine that the damaged engine is one of the two in the middle or that metal stitching did not exist when this happened. What would you do?

Welding. Welding techniques have developed a lot, but are very time consuming, due to the fact that heat causes stresses and hardening in the material, and must be done in very short sections to be able to keep the heat and the stresses on an accepted level after welding. There is also a large risk of a re-failure after welding, due to the contraction and expansion in the material caused by the welding heat. Fire safety is also a factor when considering this method.

Change the engine block. This will probably give the best end result from a reliability point of view, but it is also the most expensive and time consuming way of solving this problem. You would have to cut the ship almost in half before being able to replace the block.

When you look at metal stitching from this perspective, the actual potential of its method is clear. Metal stitching can often be performed with minimal removal of parts. It is very convenient, not least in a ship where space is a scarce.

However, the damage has to be treated and evaluated from case to case. An engine in a power station is much easier to replace than an engine in a ship. If both the engine block and the crankshaft have been damaged, and the crankshaft has to be replaced, then the engine block has to be lifted anyhow, so at the same time it might be advantageous to replace the block if the damages are more severe.

5.2 Conclusion based on tensile test

Tensile tests show very low tensile strength on the joints repaired with only screws. The first test broke already at pre tensioning. The average strength of a joint repaired with screws is 30 MPa, which is more than 15 times less than the original strength of the repaired material. Even though repaired with screws from both sides the tensile strength is so low that this can only be used on sites on the engine block where there are no accelerating forces at all. The average tensile strength of a repair with both screws and lock is 92 MPa, which is about 5 times less than the original material. But when evaluating these results, one must bear in mind that these test plates are very small, and so are the screws used. Larger screws mean larger threads, which means more strength. Also the tested joint is a straight cut joint, and the material is only 12mm thick. When repairing an engine block the material is often thicker and the joint more structural, which can add more strength to the repair. One very good way, perhaps the best one to evaluate if an engine block should be repaired by stitching, is to compare the damaged engine block with an FEM-analysis of the same type. In this way you can easily see if the damage is located in a higly stressed site on the engine block.

5.3 Conclusion based on fatigue test

Due to lack of time, the fatique test will be performed later on. More info in chapter **6, Discussion.**

6 Discussion

The intention was to have both the tensile and the fatigue test included in this thesis, but there was not enough time to be able to cope with that. The reason for this is that when performing a normal fatigue test you look for the highest level of stress that a material can cope with in an unlimited time and load shifts without breaking. However, this is not a fatigue test of a normal material, but of a repaired joint. A joint is not flexible like any other material, and the yield strength might not even exist, so to perform the fatigue test you need to know the tensile strength and yield strength (if existing) of this stitching to be able to set a starting point for the load in the fatique test. First I had to test the test plates for their tensile strength, and this was done so close to the deadline of the thesis that there was not enough time to perform the fatigue tests. However, my work with this analysis will continue and the results from the fatigue tests will be available when the conclusions are presented to my employer.

Looking back at all the work done with this analysis I think it has gone rather well. When first gathering feedback about cases where stitching had been implemented, it took a while to get any responses from the stakeholders, but then when following up on chosen installations the responses were rather immediate from the account managers. This shows that there is a need of these guidelines about where to use stitching on an engine block.

Regarding the classification societies guidelines, I could easily get in contact with the right persons working with this matter, and I got helpful comments about their perspectives of stitching. With one exception, despite several attempts I could not get a response from ABS.

One of the most time consuming phases has been to get the test parts for tensile and fatigue testing prepared. First of all it was hard to get my hands on castings that would suit both the size and the material demands. Secondly, the most time consuming task has been to get Lock n Stitch to stitch my test parts. There has been a long email correspondence between me and the CEO of LnS, Mr Gary Reed. I wanted a stitching that would be as close to the reality as possible, while Mr. Reed all the time aimed for the best result from a tensile strength point of view. Some of his proposals would be impossible to perform on an engine block, such as stitching from both sides of a cast iron wall and finger joint shaped cast iron joints. When we finally agreed on how the stitching would be done, a lot of time had flown by and the deadline for my thesis was getting very close. Last of all I want to thank all involved in this project, especially my supervisors from Wärtsilä, Mr Mats Lagström and Mr Kennet Carlström.

7 Sources

Wärtsilä internal document server, IDM.

Mail correspondance with Mr. Gary Reed

http://www.easttexasoilfield.com/#!texas-oil-field

http://www.metalockaustralia.com/metal_stitching.php#history

http://www.enotes.com/1930-business-economy-american-decades/oil-boom

Finnish Standard Association SFS, internal source.

http://www.nordicpipe.se/nyhet/nya-standarder-gjutjarn-segjarn

http://www.enginebuildermag.com/Article/1968/pinning_down_the_cold_repair_process.aspx

http://www.r-f.com/metal_stitch_repair.asp

http://www.valuatlas.fi/

http://www.metalock.co.uk/On-site_Services/Casting_Repairs.aspx

http://www.freeasestudyguides.com/engine-block-repair.html

http://www.castironrepair.com/cast-iron-repair

http://www.locknstitch.com/

http://publications.lib.chalmers.se/records/fulltext/141833.pdf

Brennert, Sven. Karleboserien, elfte utgåvan. Materiallära: Metaller, plaster, elaster, smörjmedel, keramer och trä. ISBN 91-85026-33-6.

Appendices

I. Collected repair cases
II. Tensile testing
III. Metalock approval
IV. LnS approval

Appendix I.

Lock´n Stitch repairs

on Wärtsilä engines — Follow-up

Installation	Engine type	Product no.	Additional information
Allure of the Seas	W16V46		Cylinder liner lower guidance and cam box.
Carnival Magic	W12V46		Cylinder liner lower guidance and cam box.
Puerto Plata CEPP	18V32		Petris report
Gaslog Singapore	W12V50DF		Broken HT-water channel
Nejapa	18V32		Cylinder liner upper and lower guidance.
Oceania Regatta	12V32		Cylinder liner lower guidance.
Sea Dream			Inspection hatch.
Sea Escape	8R32		Zeisured piston…
Statendam	8 ZAL 40S		Big part from engine block loose.
Soyapango	W18V32	5039	Cam box damage.
Celebrity Eclipse	W12V46	PAAE072245	Loose counterweight, many dents and holes in engine block.
Deepwater Pathfinder	18V32		Lower liner bore, cambox, and other dents and cracks.

Account manager	Phone number	Email
Maureen King	19 543 274 894	MAUREEN.KING@WARTSILA.COM
Gillian Sartini	+1 954 -383-57	GILLIAN.SARTINI@WARTSILA.COM
Mitsopoulos Dimitrios	+30 69 486893	DIMITRIS.MITSOPOULOS@WARTSILA.COM
Rojas Morales Jorge Luis	50 223 849 600	JORGE.ROJAS@WARTSILA.COM
Daniele Carbonera	19 543 274 700	DANIELE.CARBONERA@WARTSILA.COM
Sander Klaas Arnold Reuve	+1 562 -277-81	SANDER.REUVERS@WARTSILA.COM
Maureen King	19 543 274 894	MAUREEN.KING@WARTSILA.COM
Matts Andersson		MATTS.ANDERSSON@WARTSILA.COM

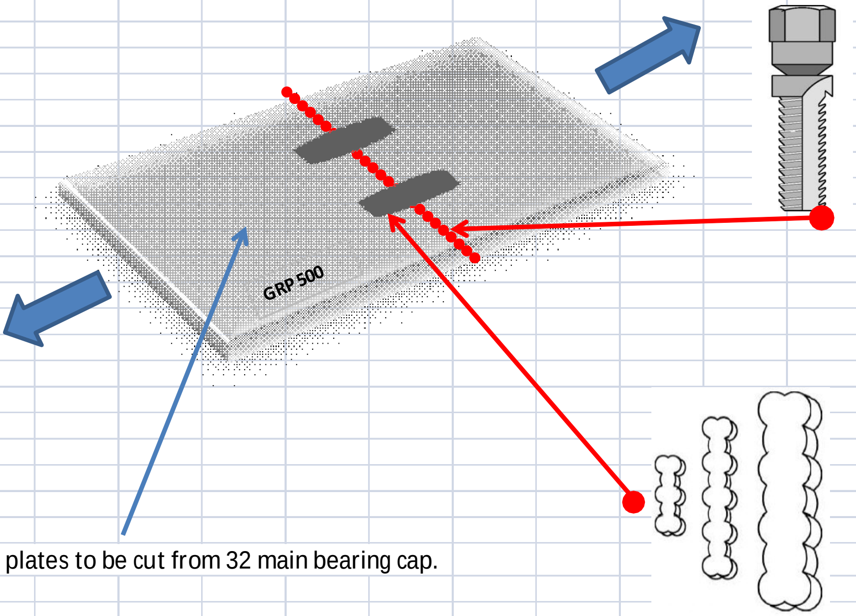
Metalock repairs

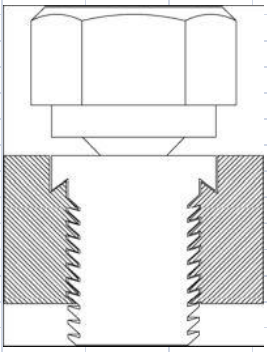
on Wärtsilä engines — Follow-up

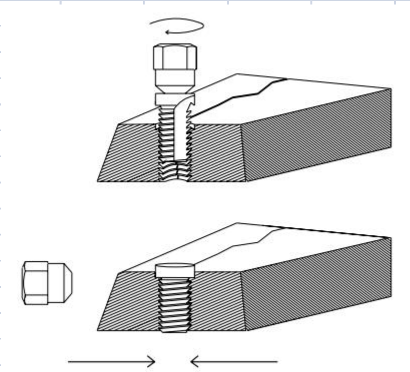
Installation	Engine type	Product no.	Additional information
M/V Kristina Regina	12V22MD-C	4270	Cylinder liner lower guidance
Azura	W12V46	PAAE091873	Charge air cooler housing
Captain FPSO	18V32	6964	?
Iberafrica	18V32	20518	Camshaft bore
Centrale BL1	W18V32	22353	Cylinder liner lower guidance
Carnival Dream	12V46	PAAE059487	Crack in crankcase hatch
Nippon Steel	18V32		Cylinder liner lower guidance
British Laurel	4L20		Gear wheel trough inspection door
Besos	W28SG		Erik Jungner tipsade om detta case.
Egasa	12ZV40/48		Cylinder liner lower guidance
Evinco			Lower liner bore
CPT Lungtan			Lower liner bore and cambox
Khulna power	18V32		Gear wheel bearing housing

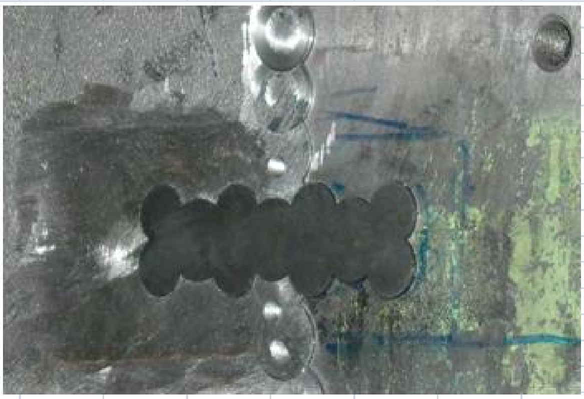
Account manager	Phone number	Email
Peltomaa Heikki	+358 40 1767582	HEIKKI.PELTOMAA@WARTSILA.COM
Peter Tedder	441 489 550 050	PETER.TEDDER@WARTSILA.COM
Timothy Burnett	4 401 224 871 166	TIM.BURNETT@WARTSLA.COM
Omondi Kenneth Katieche	25 420 712 339 337	KENNETH.KATIECHE@WARTSILA.COM
Landi Dario	393 356 100 017	DARIO.LANDI@WARTSILA.COM
Gillian Sartini	+1 954 -383-5709	GILLIAN.SARTINI@WARTSILA.COM
Miyagawa Tateo	+81 80 23364875	TATEO.MIYAGAWA@WARTSILA.COM
Anthony Bradbury	447 775 807 190	TONY.BRADBURY@WARTSILA.COM
Martinez Brunet, David	34 670 728 006	David.Martinez@wartsila.com

Tensile and dynamic test of LnS stitched parts









Certificate No: MNDE/REP/0010/04

Metalock Engineering Sweden AB
Marieholmsgatan 28-30
SE-401 50 Göteborg
Sweden

has been approved in accordance with the requirements of Lloyd's Register for the repair of specified components by metal stitching using the 'Metalock' process under the terms of the **Metalock International Association Member Scheme.**

Before any repair is undertaken, Lloyd's Register are to be informed and their agreement obtained.

This approval is subject to compliance with the requirements of Lloyds Register. Each repair must be undertaken to a written repair procedure that has been accepted by the attending Surveyor. All work is to be completed by fully trained and authorised personnel to the Surveyor's satisfaction.

The metal stitching process cannot be accepted for forgings or castings for pressure vessels, boilers, crankshafts, propellers or other components subject to cyclic loading. The acceptance of any repair as a permanent or temporary means would depend upon the merits of each case.

This Certificate is issued to the above contractor and is valid until the date given below.

Valid until:	14 October 2014
Date of issue:	26 January 2012

C D Waylen
Lead Specialist to Lloyd's Register EMEA
A member of the Lloyd's Register Group

Lloyd's Register

Certificate No: MNDE/REP/0068/01

Lock-N-Stitch Inc.
1015 S. Soderquist Road,
Turlock, CA 95380,
USA

has been approved in accordance with the requirements of Lloyd's Register for the repair of specified components by metal stitching using the **Lock-N-Stitch®, Castmaster®** and **Full-Torque®** processes.

Before any repair is undertaken, Lloyd's Register is to be informed and their agreement obtained.

This approval is subject to compliance with the requirements of Lloyds Register. Each repair must be undertaken to a written repair procedure that has been accepted by the attending Surveyor. All work is to be completed by fully trained and authorised personnel to the Surveyor's satisfaction.

The metal stitching process cannot be accepted for forgings or castings for pressure vessels, boilers, crankshafts, propellers or other components subject to cyclic loading. The acceptance of any repair as a permanent or temporary means would depend upon the merits of each case.

This Certificate is issued to the above contractor and is valid until the date given below.

Valid until: 27 January 2016
Date of issue: 28 January 2013

C D Waylen
Principal Specialist to Lloyd's Register EMEA
A subsidiary of the Lloyd's Register Group

Lloyd's Register