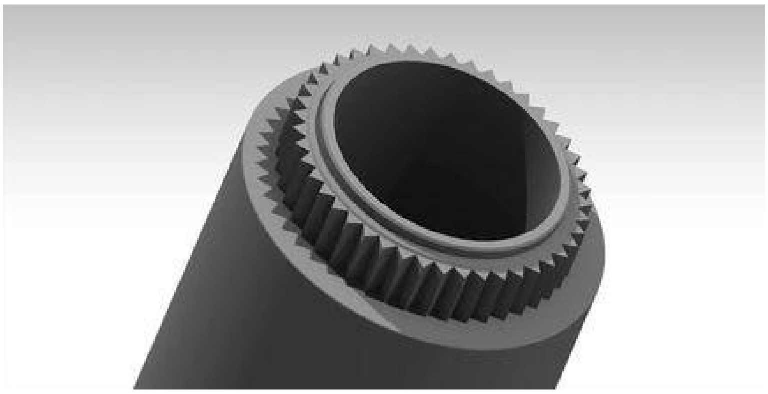

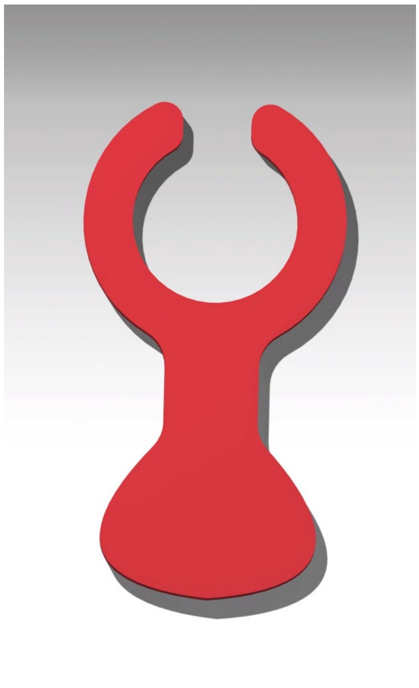

Spacer on Bracket Mounting Solution

Degree project in Mechanical Engineering, bachelor's degree

Kacper Czerniak
Jonathan Hall

Department of Industrial and Materials Science

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

Abstract

The following document is a report on a bachelor's degree project in Mechanical Engineering, which was carried out in the spring of 2022. The work was conducted under the Department of Industrial and Materials Science at the Chalmers University of Technology. The assignment, which is to develop a mounting solution for spacers and other attachments on brackets, was assigned by Volvo Penta. The reason to develop an alternative mounting solution was to solve some quality issues which were consequences of the existing solution. To establish a concept for the mounting solution a product development method was used. This included idea generation based on a requirements list using brainstorming and TRIZ, and a market analysis looking at solutions to similar problems. Elimination matrices and prototype testing were used to successively reduce the number of solutions. The resulting concepts are presented, and conclusions are drawn.

The supervisor at Chalmers was Dr. Göran Gustafsson and the supervisor at Volvo Penta Mr. Jonas Lundh.

Sammanfattning

Följande dokument är en rapport över ett examensarbete på högskoleingenjörsprogrammet i maskinteknik på Chalmers tekniska högskola som utfördes på Institutionen för industri- och materialvetenskap under vårterminen år 2022. Uppgiften, som kom från Volvo Penta, var att utveckla en metod för att fästa distanser och andra komponenter på plåtkonsoler. Anledningen till att utveckla en alternativ infästningsmetod var att lösa kvalitetsproblem med det nuvarande utförandet. Arbetet gjordes med hjälp av idégenerering baserad på en kravspecifikation genom att utnyttja metoder som brainstorming och TRIZ samt en marknadsundersökning för lösningar som har använts för liknande problem. Elimineringsmatriser och prototyptestning användes för att successivt minska antalet möjliga lösningar. De resulterande koncepten presenteras och utvärderas.

Handledare på Chalmers var dr Göran Gustafsson och på Volvo Penta Jonas Lundh.

Acknowledgments

Throughout the project, we have received exceptional help and guidance from our supervisor Dr. Göran Gustafsson, whom we would like to thank for the support.

Also, we would like to thank Mr. Jonas Lundh as well as Mr. Ola Olausson for the guidance, help, and warm reception at Volvo Penta.

Further, as all prototypes were made in the eXPerimentverkstaden workshop at Chalmers, we would like to thank for the opportunity to be able to construct the prototypes ourselves.

Contents

1. Introduction 6
1.1 The issue 7
1.2 Purpose 9
1.3 Problem statement 9
2. Problem examination 10
3. Idea generation 11
3.1 Results of the brainstorming 12
3.2 Concept presentation 13
3.3 TRIZ idea generation method 17
4. Elimination of inferior concepts 19
4.1 Elimination result 23
4.2 Prototype building and testing 23
4.3 Testing process 29
5. Refinement and further development of the resulting concepts 30
6. Conclusion 31
7. Discussion 33
7.1 Discussion of the result 33
7.2 Discussion of the approach 33
References 34
Appendix i
Criteria list i

1. Introduction

Volvo Penta is an international industrial engine and marine propulsion system manufacturer with their headquarters located in Gothenburg and manufacturing plants in Sweden, China, and USA. Volvo Penta is part of the Volvo Group, which also includes Volvo Trucks, Volvo Construction Equipment, Volvo Buses, and many other companies within the transportation sector.

Several Volvo Penta diesel powerplants are modified Volvo Truck engines, and most products manufactured and sold are diesel engines ranging from around 10 to 1000 horsepower. Volvo Penta diesel engines are primarily used for industrial and marine applications. Industrial applications include heavy machinery and so-called gensets. A genset is a generator and engine module. These are used worldwide, either as primary electric power supply when the normal power grid is not an option, or as backup generators for hospitals, powerplants, airports, etc. The Volvo Penta marine engines are used on boats ranging from smaller leisure crafts to big yachts and commercial ships. These two areas make up about 50% each of Volvo Penta's production. The diesel engines are mainly produced in the Swedish production plants in Vara and Skövde, but they are also assembled in Lingang, China. The whole gasoline engine production is in Lexington, Tennessee, USA.

Volvo Penta is very environmentally conscious and is now expanding in the electrical propulsion system segment. A further market that Penta takes part in is marine drives and transmissions. These are produced in the Swedish city Köping.

1.1 The issue

In most diesel engine platforms and gasoline engines, brackets with spacers and different attachments are used to interconnect parts with one another as seen in *Figure 1,* in which an assembly for an external engine heater is shown.

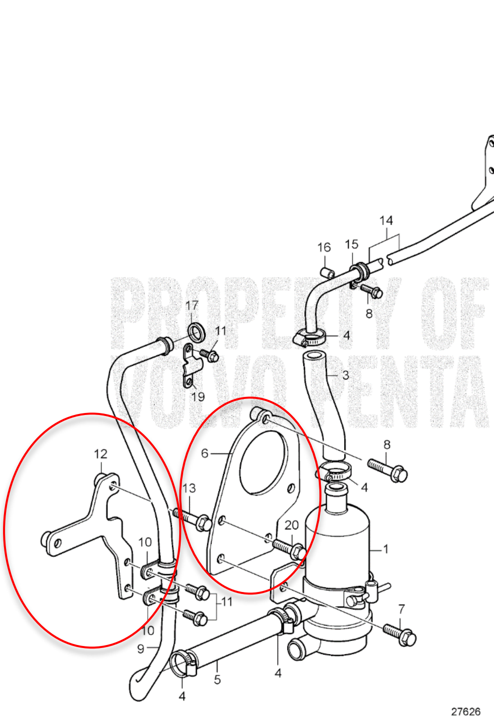

Figure 1. An assembly of an external engine heater for a Penta D12 engine. Parts 6 and 12 are brackets with spacers.

The brackets are premade by subcontractors. The spacers and other attachments are MIG/MAG-welded into place to improve the handling while manufacturing, as well as to facilitate logistics. A welding jig is used to position the spacers on the bracket. This method has several drawbacks. One is that the steel in the heat affected zone (HAZ) often degrades during welding. Depending on the carbon grade and alloying grade, the material becomes softer or brittle and prone to corrosion. The process can also introduce internal stresses and microscopic cracks (Ashby et al., 2018). Thus, when the welded brackets are loaded and subjected to vibrations from an engine, the microscopic cracks in the steel can begin to grow like in *Figure 2*. This can result in failure of the brackets with possibly disastrous consequences.

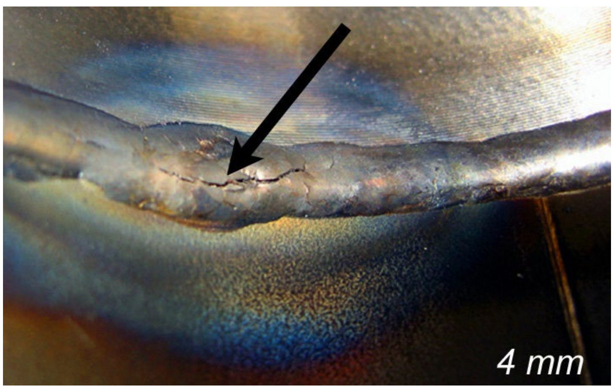

Figure 2. Cracked weld.

The effects of the HAZ can for the most part be prevented in several ways. The methods can be sorted into two categories: pre-weld and post-weld treatment. The first amounts to restricting the heat output, pre-heating of the workpieces and use of chill blocks to extract heat from the welded area during the process. Post-welding treatment includes reheating of the affected material to restore its properties and use of heating blankets to slow the cooling of the workpieces.

Furthermore, the welds often have complicated geometries and sharp edges. This makes it difficult to put coating on them, which in turn leads to corrosion issues.

The main reason for having spacers on brackets is to offset certain parts of the engine from the engine block. This aids in packaging the engine and engine accessories, and it also prevents heat and vibration transfer. The second most important reason for using spacers is to make it possible to use a longer bolt and thus obtain more clamping length to reduce the risk of the bolt loosening or breaking due to fatigue. Most brackets and spacers are made of general construction steel. If the spacer is to be welded onto the bracket, both need to be made of welding compatible materials. To protect the brackets from corrosion, they are either zinc coated, or powder coated (Swedish Fasteners Network, 2016).

1.2 Purpose

The purpose of the project presented in this report is to develop a method for fixing spacers onto brackets in a way that solves the issues, mentioned above, that derive from welding them in place. It is an advantage if the new method also allows for easier mounting on the production line in the Volvo Penta factory, for example with fewer parts to assemble, to reduce the cycle time. Furthermore, optimized geometry can perhaps also make it easier to stack and transport the components.

1.3 Problem statement

Volvo Penta has been producing engines with these sorts of brackets for a long time, and it can be demanding to introduce a new method for something that has been done a certain way for years. To come up with a good product, certain objectives must be reached. These include:

Solve the problem with worsened mechanical properties caused by the current method

The present method involves welding, which, as described earlier, creates a heat-affected zone around the weld.

Be more corrosion resistant

The welding geometry and the gaps between the spacer and bracket cause areas where the paint coating does not reach when applied and makes the part prone to corrosion.

Durable enough

As the brackets are transported in large quantities on pallets and handled manually, the fastening solution must not fail when it is dropped from the height of an average human on a hard surface, like a concrete floor. It must also withstand the vibrations and the heat from the engine which it is mounted on, as well as splashes of salt and fresh water and occasional sunlight (UV).

Mass production compatible

The solution must be possible to produce in a large quantity at a cost comparable to the present solution.

Delimitations

The bracket and other parts will not be geometrically redesigned to fit the new mounting solution. Furthermore, cost is not a factor which will be considered in the early stages of the process, for example during the idea generation.

2. Problem examination

In the initial stages of the project, the current fastening method was evaluated and examined, and a few conclusions could be drawn. The current engine platforms were studied to determine the number of brackets and their placement, and the placement and numbers of the spacers and other attachments. Also, a crucial factor is how the attachments are welded into place.

Firstly, there are around seven brackets on each diesel engine platform, and each of these has on average three attachments. This means that each engine platform has around 21 spacers or nuts welded onto the brackets. Since there are many attachments, there is huge room for improvement when it comes to the method for fastening these onto the brackets. An improved solution could potentially come with both financial and quality benefits.

Furthermore, the key issues with the current solution were introduced by the supervisor. These were foremost quality issues deriving from welding and corrosion. The bracket and the process of manufacturing it was therefore studied. The reason for welding the attachments in place is to improve logistics as well as the handling of the parts on the production line.

The study of the bracket and the problems presented by Volvo Penta were used to create a criteria list (see *Appendix*) which contains the requirements on as well as wishes for the final solution.

3. Idea generation

The goal is to generate as many potential solutions as possible, by using different idea generation methods. This while being objective and not ruling out any possible solutions in this stage.

The main idea generation method used was brainstorming, during which spontaneous ideas originating from the group members are listed. When using it, one should try to produce as many ideas as possible for a viable solution.

The process of brainstorming initially began by studying the brackets fitted to engines in the Volvo Penta engine testing facility in Gothenburg. Later, the first brainstorming session began in which we both wrote down all ideas that came into mind. These were then summarized, and later a second round of brainstorming was carried out and later even a third one. The sessions were about one hour each, and past-session ideas that came into mind were also written down.

Another idea generation method used was TRIZ, which tries to find a solution to a problem on the basis that someone has already found a solution to a similar problem. This is then adapted to the specified problem. The method demands a wide database of patents and technical solutions and is time-consuming. Solutions to similar problems in other fields were studied to see if they also solve the current problem.

3.1 Concepts by brainstorming

The process of brainstorming initially began by studying the brackets fitted to engines in the Volvo Penta engine testing facility. Later, the first brainstorming session began in which we both wrote down all ideas that came into mind. These were then summarized, and later a second round of brainstorming was carried out and later even a third one. The sessions were about one hour each, and past-session ideas that came into mind were also written down.

3.2 Results of the brainstorming

Designation	*Concepts*
A	Improving existing design
B	Alternative welding method (laser welding)
C	Cast in one piece
D	Expanding bushing
E	Friction welding
F	Glue
G	Magnetism
H	Press/shrink fit
I	Retaining ring
J	Rivet
K	Set screw
L	Snap attachments
M	String or belt
N	Tape
O	Pop-nut method
P	Press/grip attachment (self-clinching nut)
Q	Spot welding
R	Threaded

Table 1. Concept list.

3.3 Concept presentation

Concept A
The first natural thing to do is to improve the current solution, which is welding the spacer in place. It could be improved or re-engineered to eliminate the earlier mentioned drawbacks of the method.

Concept B
The alternative welding concept (*Figure 3)* was a general idea that was to be investigated and evaluated further into the process.

Figure 3. Laser welding.

Concept C
The casting concept (*Figure 4)* means casting the bracket and spacer as one piece. There are multiple different casting methods that could be used in this application. The different castings methods would need to be evaluated further.

Figure 4. Casting.

Concept D
The using of an expanding bushing in the interface between the spacer and the bracket. *(Figure 5).*

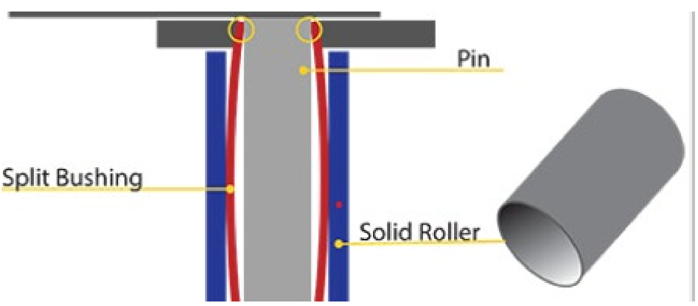

Figure 5. Bushing between a plate and a spacer (solid roller).

Concept E
The friction welding concept (*Figure 6)* involves the use of friction to fuse the parts.

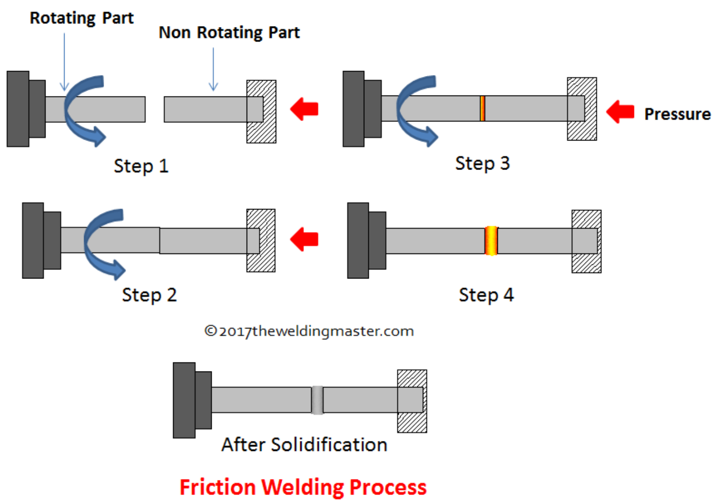

Figure 6. Friction welding.

Concept F
The glue concept (*Figure 7*) is based on using glue to bond the pieces together.

Figure 7. Glue.

Concept G
The concept of using magnetism (*Figure 8*), either by separate magnets or magnetizing a part was listed.

Figure 8. Screws stuck to a magnet.

Concept H
The press/shrink fit concept, in which steel parts are precisely machined for them to grip each other (*Figure 9)*.

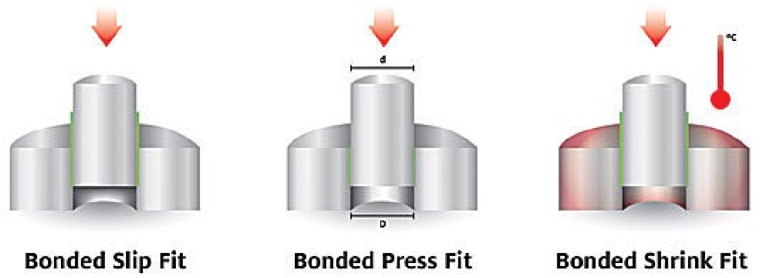

Figure 9. Different press/shrink fits.

Concept I
The retaining ring concept (*Figure 10)* locks the parts together.

Figure 10. Different retaining ring designs.

Concept J
Hot riveting concept *(Figure 11)* means adapting the process of using hot rivets to fix the spacer to a bracket.

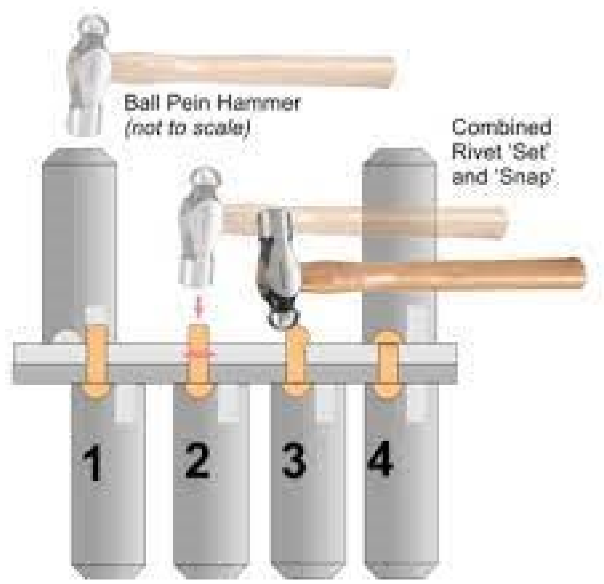

Figure 11. Hot riveting.

Concept K
The set screw concept is to use a set screw to interlock the parts *(Figure 12)*.

Figure 12. Set screw locking a bar in place.

Concept L
The snap fit joint concept (*Figure* 13) was to adapt a snap-on interface to lock the spacer and bracket together.

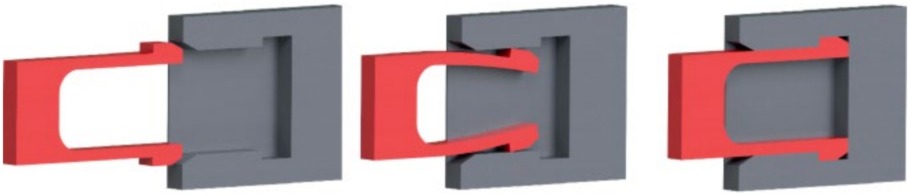

Figure 13. Snap fit joint.

Concept M
The concept for using a string (*Figure 14)* to tie the pieces together.

Figure 14. Objects (keys) tied with a string.

Concept N
The tape concept is using tape to hold the parts together (*Figure 15)*.

Figure 15. Tape, that could be applied.

Concept O
The fifteenth idea that came up, so-called pop nuts, works best on thin plates. A tube is inserted into a hole, and a part of it is deformed axially so that it grips the plate as seen in *Figure 16*.

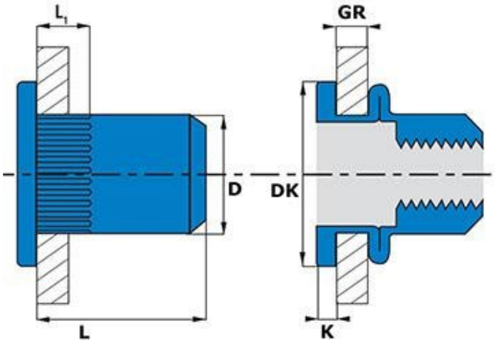

Figure 16. Pop-nut before and after mounting.

Concept P
A lesser-known solution which is used on press nuts is shown in *Figure 17*, where the nut is pressed into place. The corrugated surface on the nut makes up for tolerance for a press fit. This allows for a production method that does not require very precise machinery. A large manufacturer of self-clinching press nuts is Bossard. *Figure 17* shows a Bossard self-clinching nut. It is easily pressed into place using a hydraulic or arbor press.

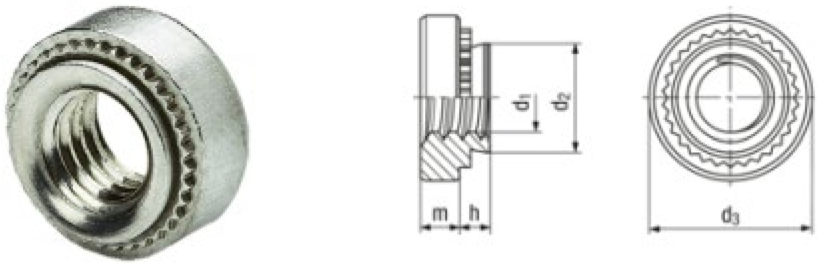

Figure 17. Self-clinching nut from Bossard.

These 16 concepts were generated through brainstorming, to further generate ideas another method was used.

3.4 TRIZ idea generation method

To find solutions to the problem at hand, some concepts from the TRIZ method was used, specifically.

- Generalizing the problem as much as possible. In this case attaching components.
- This generalization of the problem can then be used to find solutions to similar problems across different fields. In this case by studying different patents and commercial products that solve similar issues.
- Exploring the pros and cons of the different solutions.

After concluding the above, worldwide databases could be scanned in search for different solutions where two steel structures were combined. This resulted in the two following concepts.

Concept Q
A solution could be to use spot welding as seen in *Figure 18*. The current flows through the metal parts, and the resistance makes the steel melt and the parts fuse.

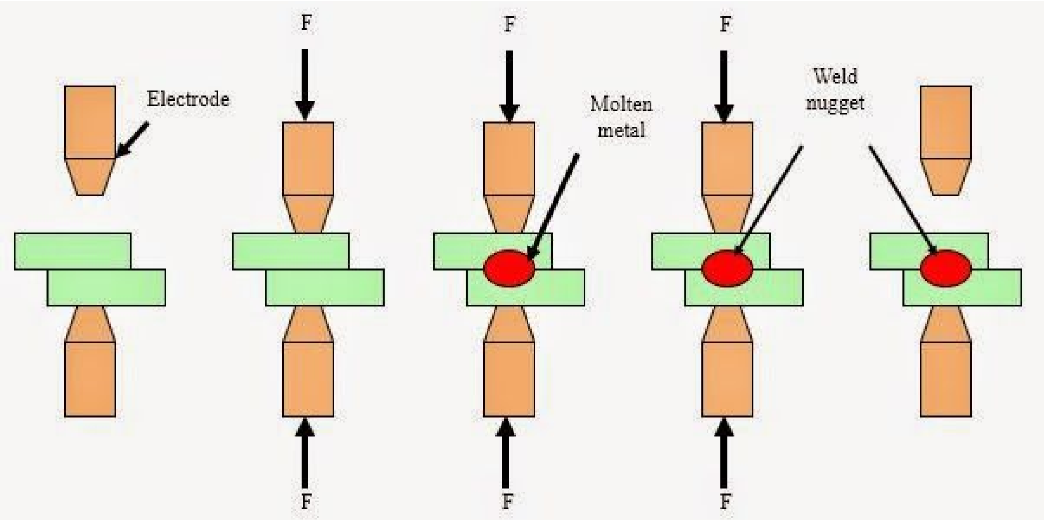

Figure 18. Spot welding principle.

Concept R
Threads could be used to attach the spacer to the bracket, as shown in *Figure 19*.

Figure 19. Threaded plate.

4. Elimination of inferior concepts

The ideas in *Table 1* were then systematically checked with respect to the stated requirements (see the Appendix), and those which did not meet all of them were eliminated.

Chalmers	+	Pass									
	?	More Info required									
	-	Eliminated									
	Requirements										
	Minimal strength	Durability	Temperature range	Enviromental Conditions	Last complete life cycle	Size compatible	No harmful materials	Protective coating	Mass producable	Vibration resistant	Suitable thermal expansion
Possible concepts											
A. Improving existing design	?	?	?	?	?	?	?	?	?	?	?
B. Alternative welding method	+	+	+	+	+	+	+	+	+	+	+
C. Cast in one piece	+	+	+	+	+	+	+	+	+	+	+
D. Expanding bushing	+	+	+	+	+	+	+	+	+	+	+
E. Friction welding	+	+	+	+	+	+	+	+	+	+	?
F. Glue	+	?	?	+	+	+	?	?	?	+	-
G. Magnetism	?	?	+	+	+	?	+	+	+	+	+
H. Press/shrink fit	+	+	+	+	+	?	+	+	+	+	+
I. Retaining ring	+	?	+	+	+	?	+	+	+	+	+
J. Rivet	+	?	+	+	+	+	+	+	+	+	+
K. Set screw	+	+	+	+	+	?	+	+	+	+	+
L. Snap attachments	+	?	+	?	+	?	+	+	?	+	+
M. String or belt	+	+	+	+	+	+	+	+	+	+	+
N. Tape	+	-	-	+	+	+	+	?	?	+	+
O. Pop-nut method	+	?	+	?	+	+	+	+	+	?	+
P. Press/grip attachment	+	?	+	?	?	+	+	+	+	+	+
Q. Spot welding	?	?	+	?	+	+	+	+	+	+	+
R. Threaded	+	+	+	+	+	?	+	+	?	+	+

Table 2. Requirement-based elimination matrix

In the elimination matrix in *Table 2*, the glue concept F was eliminated on the basis that it would not provide sufficient thermal expansion and could fail when the parts have different temperatures.

The tape concept N was eliminated on the basis that the adhesive on commercially available tape does not provide sufficient adhesive properties at low temperature.

The remaining concepts were then taken into *Table 3* for further elimination, where their achievability was evaluated.

Chalmers	Elimination matrix for mounting solutions	
	+	Pass
	?	More info required
	-	Failed/Eliminated
Possible concepts	Achievable	Conclusion
A. Improve existing design	+	+
B. Alternative welding method (laser welding)	?	+
C. Cast in one piece	-	-
D. Expanding bushing	?	+
E. Friction welding	-	-
G. Magnetism	-	-
H. Press/shrink fit	+	+
I. Retaining ring	+	+
J. Rivet	+	+
K. Set screw	+	+
L. Snap attachments	?	+
M. String or belt	+	+
O. Pop-nut method	?	+
P Press/grip attachment	+	+
Q. Spot welding	?	+
R. Threaded	+	+

Table 3. Achievability-based elimination matrix.

Three concepts were eliminated in the elimination matrix in *Table 3*.

Concept C, which is to cast a whole bracket with the spacer geometry and nuts, requires a complete readjustment of the production line. The cost per unit will also be quite high since most of the engines produced have minor dissimilarities. This creates a need for numerous different castings which quickly becomes expensive, thus this concept is eliminated.

Concept E is eliminated as it requires expensive machinery which is not available in most machine shops that are likely to be subcontractors for Volvo Penta. The heat from friction welding has of course the same impact on material properties as the heat from other types of welding has.

Concept G, using magnetic parts was quickly ruled out as this method would prove unhandy when it comes to the logistics. The parts would stick to other metal surfaces and to each other and thus, be difficult to handle.

To determine if the remaining concepts shown in *Table 3* are applicable for the contractor or not, further information had to be gathered by research into the actual solutions, as there were several questions that needed to be answered.

Concept A. Improving existing design
The current design could be improved by changing the methods of welding and paint coating. This means that the parts would have to be fully welded and not just tack welded as they are today. That would however require even higher temperatures, which would increase the heat-affected zones. Also, excessive heat will induce warping of the bracket and poor positional tolerances, which can cause further issues on the assembly line. Further, the welds could also be scanned ultrasonically for imperfections. These methods are however costly and would increase the manufacture time. They also require a welding jig to position the spacers. Thus, improving the current design is eliminated as a solution.

Concept B. Laser welding
The only suitable alternative welding method found later in the process whilst using TRIZ was laser welding, as it creates a minimal heat affected zone as well as laying down the welds so finely that only minimal imperfections are caused. Laser welding is a quite costly method as the machines needed are expensive and to date quite rare in the industry. The welding itself causes a small heat-affected zone as the welds are laid down quickly with close to no imperfections if the operator is experienced. This method could not be tested and is unavailable for most suppliers. Laser welding can however be a good solution in the future, when it is widely available. But due to unavailability solution B is eliminated.

Concept D. Expanding bushing
The issue that comes with this solution is that if the bushing is a one-time use item, they will need an extra handling process on the assembly line. They would have to be thrown away, which would not be in line with Volvo Penta's goal of being a world leader in sustainable power solutions. If the bushing were multiuse items, they would still wear down and cause waste since they would have to be collected and transported back to the facilities producing the brackets. Again, this would cause a lot of additional steps in the production process and foremost a lot of pollution, and that is why this concept is eliminated.

Concept H. Press/shrink fit
The press/shrink fit concept can not be fully evaluated without building and testing a prototype and is retained.

Concept I. Retaining ring
The retaining ring concept needs further evaluation by prototyping and testing and is therefore not eliminated.

Concept J. Rivet
This method involves heating the spacer to a temperature where the metal becomes soft enough to make it possible to deform around the hole in the bracket. The method also requires a special machine for every riveted spacer to be placed correctly and aligned, or a very skilled worker, and even then, a jig holding it in place when pounded by hand. Either way, with hot riveting it is difficult to ensure precise fit and no damage to the inner hole, since traditional rivets are solid (Preece, 2019). There are multiple difficulties associated with riveting for example accuracy. Therefore, concept J is eliminated.

Concept K. Set screw
Using a set screw, a hole must be drilled in the edge of the plate, or an additional part locking the screw must be added. In the case of drilling a hole in the plate, this is exceedingly difficult to achieve in the case of a thin plate where the spacer is to be mounted far away from any edge. In the case of

an additional part locking the spacer, bracket, and screw together, it would add complexity and require disassembly before mounting on an engine. Both solutions would result in a larger assembly and longer production time, as each bracket would have to be loosened from the set screw first and the set screws would have to be taken care of. Therefore, concept K is eliminated.

Concept L. Snap attachments
Snap-attachments could not work as the parts are made of steel, which compared to plastics has inferior plasticity characteristics (Ansys Granta EduPack, 2020 r). This means that the parts would have to be machined with exceptionally fine tolerances to be able to clip onto each other. Furthermore, the parts would still have a bit of play, which would make the paint coating crack and make room for rust. The fine machining tolerances and advanced geometry needed would mean very high production costs, and it is the main reason why concept L is eliminated.

Concept M. String or Belt
The issue that comes with this solution is that if the string or bushing is a one-time use item, they will need an extra handling process on the assembly line. They would have to be thrown away, which would not be in line with Volvo Penta's goal of being a world leader in sustainable power solutions. If the string and bushing were multiuse items, they would still wear down and cause waste since they would have to be collected and transported back to the facilities producing the brackets. Again, this would cause a lot of additional steps in the production process and foremost a lot of pollution, and that is why this concept is eliminated.

Concept O. Pop-nut method
The pop-nut method requires further evaluation through prototype building and testing and is therefore retained.

Concept P. Press/grip attachment
The Press/grip attachment requires further evaluation through prototype building and testing and is also retained.

Concept Q. Spot welding
The spot-welding concept needs further evaluation by prototyping and testing and is retained.

Concept R. Threaded
The threaded concept cannot be fully evaluated without building and testing a prototype and is therefore retained.

4.1 Elimination result

In summary, the concepts A, B, C, D, E, G, J, K, L, and M were all eliminated for previously stated reasons. This leaves the six possible solutions, shown in *Table 4*.

Concept designation	*Solution*
H	*Press/shrink fit*
I	*Retaining ring which keeps bracket, spacer and bolts together*
O	*Pop-nut style*
P	*Press/grip attachment*
Q	*Spotweld*
R	*Threaded*

Table 4. Remaining solutions

4.2 Prototype building and testing

The number of solutions must be further reduced to obtain one to three possible solutions to present. The remaining alternatives must be better understood to be able to do that. To gather more practical information for the continued evaluation and elimination process, prototypes must be built and tested. This illustrates their overall manufacturability, which is one of the factors to evaluate. Some concepts might be difficult to build.

To test the durability and strength of the spacer attachment solution, impact tests will be carried out. The timeframe does not allow for an extended period of corrosion testing, but corrosion resistance will be analyzed with respect to the size of the gap between the plate and spacers, and whether the parts can be completely covered with a protecting coating without the risk of chipping it.

All six prototypes are all the remaining concepts attached to a piece of sheet metal. The sheet is 4 mm thick, which is a common thickness for brackets at Volvo Penta.

Concept H

Press/shrink fit

Using a press/shrink fit to fix the spacer to the bracket allows for easy assembly and does not leave a gap which makes it susceptible to corrosion. The heat involved in the deformation of steel is negligible, so the material properties are not significantly affected. This solution also allows for different materials to be used in the bracket and the spacer. The disadvantage of this solution is that it requires precise machining, which is expensive and time-consuming. Making the spacers with the necessary tolerance should not add much cycle time, since turning down the diameter slightly does not require much time. But reaming the holes in every bracket adds a lot more manual work to set up and machining. The concept is eliminated due to its mentioned disadvantages.

Figure 20. Press/shrink fit prototype.

Concept I

Retaining ring

The prototype was easy to manufacture as the only part needed is a retaining ring. The prototype for this was 3D printed in a plastic material. Making it from plastic. The main advantage of this solution is that all surfaces can be painted or zinc-coated before mounting the spacer onto the bracket.

This method also allows each screw to be pre-mounted with all the parts needed for assembly. Since there is no welding involved, the material properties are not affected, and dissimilar materials can be used. The spacer is not permanently mounted onto the bracket and there is therefore no risk of it being mounted out of tolerance, so there should be no issues related to tolerances. Since the solution only requires hand assembly, no special equipment is necessary which makes it cheap.

Figure 21. Retaining ring prototype assembled.

Figure 22. Retaining ring prototype.

A disadvantage of the retaining ring concept is that it can create a lot of waste if the ring is discarded after the first use. Although made from plastic, the retaining ring prototype allows for multiple use, so introducing a system for the retaining rings to be collected and reused multiple times reduces waste. This concept is still viable since the disadvantages can be solved.

Concept O

Pop-nut style

To build a prototype, a traditional pop-nut was pressed onto the standard 4 mm steel plate like other prototypes, after which a spacer was to be welded. After pressing the pop-nut to the sheet metal, a gap and a slight jiggle could be observed. This small movement would chip off paint, and the unprotected metal and gap would trap moisture and lead to rust forming. Also, the collar on the opposite of the bracket can cause clearance issues. Thus, this solution was eliminated even before welding the spacer to it.

Concept P

Press/grip attachment

To manufacture the prototype, a press nut was welded to the spacer, though the actual spacers intended for each bracket would be manufactured in one piece. When using a press/grip interface on the spacer, all the surfaces can be covered with a protective coating and the gap between the spacer and bracket was observed to be small. There is no welding involved and the heat deriving from pressing is negligible, therefore the material properties will not be affected. The solution does not require any precise manufacturing processes, assuming that the spacers are manufactured by a machine element producer like the one manufacturing press nuts. The press nut interface can be mounted in a drilled or laser/waterjet/plasma-cut hole with no reaming required. Since the spacer is pressed into the hole, no jig or special machinery is required, which is the case for the existing method. Thus, the solution is viable.

Figure 23. Press/grip prototype. *Figure 24. The self-clinching interface on a spacer.*

Concept Q

Spot welding

The prototype was manufactured by welding a spotweld nut to the spacer and then spot welding the spacer to a piece of sheet metal. An advantage of this solution is fast manufacturing since spot welding has a shorter cycle time compared to MIG welding. The manufacturing time is also decreased since the parts do not need to be secured to a welding jig. The disadvantage, which eliminates this solution, is the large gap between the spacer and the bracket which would cause corrosion. With welding involved, the material properties would also be affected.

Figure 25. Spot welded prototype.

Figure 26. Spot welded prototype.

Concept R

Threads

A thread with a 2 mm pitch and a bracket made of a 4 mm thick steel plate are needed to fit the screw. This means that only two complete threads are in contact, which makes the connection poor. The pitch used could be finer, and a thicker plate would also improve the fit. Increasing the thickness of the bracket will increase the mass, material cost, and waste. The solution also needs to be universal to work with many different sheet metal thicknesses in different brackets. A screw is susceptible to loosening when subjected to vibrations, and the alignment is not guaranteed to be correct if the plate is thin and the threads are coarse. The threads would settle under load causing the paint coating to crack and give way to rust. Also, two parts need to be threaded, which increases the complexity of the parts. That is why this solution is eliminated.

Figure 27. Threaded prototype.

Figure 28. Threaded prototype.

4.3 Testing process

The remaining solutions after evaluation of manufacturability during the prototype building are I and P. Prototypes of the remaining solutions were then dropped onto a concrete floor. This is the fastest, cheapest, and in this case most realistic way of testing durability. The first drop test was from a height of 1.5 meters, simulating a normal drop case on the assembly line or while handling. All the prototypes passed 5 drops from 1.5 m. The second drop test was 5 times from 4 meters to simulate a heavier bracket since the prototypes are lighter than an actual bracket. The press fit between the sheet metal and spacer lost its grip. Since it failed the drop test and is expensive to manufacture it is eliminated. Thus, only solutions I and P, which are, the retaining ring and the press/grip attachment remain. These solutions solve the issue. They have some different pros and cons and could be mixed depending on the specific application. Both concepts could be further developed.

Figure 29. Retaining ring (Concept I).

Figure 30. Press/grip interface (Concept P).

5. Refinement and further development of the resulting concepts

There is always room for improvement when it comes to material, product, and technical solutions and this project is of course no exception.

Concept I, which is the retaining ring could be further improved by including a handle or string to pull the retaining ring from the screw when it's already screwed into the engine. Other designs can also be developed to further improve handling and ergonomics for the assembly workers. This would also mean that the retaining rings can be tied together or attached in some other way, which makes them easier to reuse. The retaining ring snaps into the thread of the screw with the U-shaped end and the handle is used to easily remove it when assembling the bracket and the engine.

Figure 31. Improved version of the retaining ring (Concept I)

An improvement of concept P, which is the press/grip attachment, the bracket and the spacers can be zinc-coated before pressing them together, as this would further improve corrosion resistance. The design of the slots/splines seen in *Figure 30* could also be optimized to make the spacer easier to push down and further reduce the gaps between the parts.

6. Conclusion

Concluding the study, several concepts were systematically narrowed down to only two concepts, namely the retaining ring and an adaptation of a press nut which is the press/grip attachment. These concepts both solve the issues with corrosion and material failures, and they are strong enough not to fail during transport and handling. Below the concepts are analyzed based on how well they fulfill the objectives set earlier.

Figure 32. Retaining ring (concept I).

Figure 33. Press/grip interface (Concept P).

The retaining ring and the press nut concept are both possible solutions. They have many dissimilarities and different advantages. The retaining ring solves a so-called non-stated issue which is that the appropriate screws can be previously mounted, which could speed up the assembly time and make it easier for the workers mounting the brackets. This would however also mean that the assembly line must be adjusted to fit the solution as the retaining ring has to be incorporated in the production.

Therefore, if Volvo Penta and subcontractors choose not to adjust the assembly line to incorporate the retaining ring solution, then the self-clinging nut interface is the appropriate concept. This does not interfere with the current assembly process, it eliminates the need for welding, and it increases the corrosion resistance.

The earlier stated objectives in the problem formulation are:

- **Solve the problem with worsened mechanical properties caused by the current method**

As mentioned before, neither of the two selected attachment methods includes any heating work, and thus does not run the risk of worsened mechanical properties because of the welding.

- **Be more corrosion resistant**

Both solutions passed as they were less prone to corrosion than the current solution. The corrosion resistance was, as mentioned earlier, assessed with respect to the size of the gap and the geometry. There are several other phenomena, for example galvanic corrosion, that could have an impact.

- **Durable enough**

The drop tests were a good representation of what may happen to bracket during handling and mounting, although a more scientific approach would be to conduct Charpy impact tests.

- **Mass production-compatible**

Both solutions can easily be mass-produced as the production methods are widely available. The retaining ring concept can be produced using injection molded plastic or stamping out of a thin plate. The quite simple geometry and cheap material imply a low unit cost when manufactured in large quantities. A retaining ring would have to be produced in a couple of varied sizes to fit the varied sizes of screws.

The self-clinching interface on the press/grip concept could be manufactured using similar machinery as the ones used when manufacturing self-clinching press nuts. The Press/grip spacer concept would have to be produced in various sizes and different lengths to suit different diameters and lengths of bolts. Both concepts are likely to be manufactured by a subcontractor, since the subcontractors manufacturing the rest of the brackets are at present unlikely to have the capabilities and machinery to produce either of these concepts.

7. Discussion

In this chapter, the approach, as well as the result, will be discussed and analyzed with respect to the objectives stated earlier in the process.

7.1 Discussion of the result

The research conducted at the beginning of the project, was based on the stated issues with the current solution. The principal parameters that affect the mounting solution the most are rust, material fatigue caused by heat-affected zones, and the strength of the attachment. These parameters were focused on when each solution was studied. The way of analyzing with respect to these parameters could be further improved. Corrosion properties, for example, were mostly assessed by the size of the gap left between the spacer and bracket, and there are more qualified ways to do that.

7.2 Discussion of the approach

An alternative method of elimination would be to build full-size brackets with properly machined and applied solutions. But it's quicker and more cost effective to build simplified smaller brackets only containing the spacer to bracket attaching interface. The scale-down or simplification of the prototypes could mean that the tested solutions give a false result as the fuse-method could have a limit value of stress when it collapses, that is not reached when the prototypes weigh as little as they do. This was compensated for by dropping them from a height that is larger than the brackets would usually have to endure. Therefore, this prototype testing is cost and time effective and sufficiently accurate.

Another factor in a product development process is time, which is always a limiting factor in these circumstances. This is most likely that the proposed solutions could be analyzed and further developed more thoroughly if given more time. Although the time spent, and cost must always be balanced against each other when it comes to product development work for companies as it increases the final cost of a product.

The work carried out has in our opinion gone according to plan and easy with a few minor obstacles and unexpected difficulties, e.g., when the concept elimination stalled because of the lack of information. It was then decided that prototypes would be built to gather more information by physically test the concepts. A further factor which could have made a positive impact on the work and would be good to carry out next time is to interview the assembly workers, this would give input from people with hands on experience. Some more tests of the prototypes could have been to evaluate other properties of the concepts for example corrosion tests or vibration and fatigue life tests.

With all facts on hand, the most important step in a product development process is gathering all the information possible of all the aspects of the environment, use, life, production etc. of the product. Furthermore, one should always avoid being constrained by established methods and thoughts.

References

Bossard Holding AG, (2022), *BN 20599 - Self-clinching nuts for metallic materials*, collected (2022/05/30), Product data sheet from URL: https://www.bossard.com/eshop/se-en/clinching-technology/clinching-clinch/selfclinching-nuts/pem-clsclss/p/20599/

Database by: Ansys Granta EduPack, 2020 r, (collected 2022/05/30), URL: https://www.ansys.com/products/materials/granta-edupack

E. Preece, (2019), *What is hot riveting and how is it used?*, bdcmagazine.com, (collected 2022/05/30) URL: https://www.bdcmagazine.com/2019/08/what-is-hot-riveting-and-how-is-it-used/

M. Ashby, H. Shercliff, D. Cebon, (2018), Materials Engineering, science, processing, and design (3rd edition), Butterworth-Heinemann

M. Mägi, K. Melkersson, M. Evertsson, (2018), Maskinelement, (2nd edition), Dimograf

Swedish Fasteners Network, (2016), *Handbok för skruvförband,* (collected 2022/05/30), URL:*http://handbok.sfnskruv.se/template.asp?lank=173*

Volvo Penta, (date unknown), *Toward sustainability*, volvopenta.com, (collected 2022/05/30), URL: https://www.volvopenta.com/about-us/toward-sustainability/

Appendix

Criteria list

Requirements on and wishes for the potential solution.

Chalmers	**Document Type**	Criteria list				
Project			Spacer mounting solution			
Issuer: Kacper Czerniak & Jonathan Hall		***Created:*** 2005-10-13				
Modified: 2024-02-18 by Kacper Czerniak and Jonathan Hall						
Criteria	**Goal value**		***R(requirement) /W(wish)***	***Weight***	***Method of verification***	***Reference***
	Main function					
Keeping spacers, nuts, and bolts in place on sheet metal brackets during handling						
1. Performance						
1.1	Minimal strength	Clamping force from the bolt	R		Calculation and/or FEM	Current design/material data
1.2	Increase strength	More than clamping force from the bolt	W	4	Calculation and/or FEM	Current design/material data
1.3	Durability	Should be strong enough to endure impacts deriving from handling	R		Physical test or FEM	Current design/ not failing
2. Environment (surrounding)						
2.1	Temperature t while handling and use -50 ºC< t <700 ºC	Surviving the maximal engine operation temperature and lowest temperature engine could be subdued to.	R		FEM and/or material properties tables	Material properties
2.2	Conditions while handling and use	Weather conditions and mildly corrosive liquids	R		Material properties table	Current design
3. Life						
3.1	Life	Same as assembly and engine life	R		Fatigue test	Current design
4. Size						
4.1	Must not greatly exceed the dimensions of the current design	Must fit within the bracket	R		CAD software	Current design
5. Mass						

5.1	Low cost	Not exceed the current design	W	2	Calculating production cost	Current design
5.2	Mass	Lighter than the current design (fully welded)	W	1	Calculating using CAD software	Product planning
6. Ergonomics						
6.1	Ergonomics for warehouse workers and assemblers	Ergonomics for warehouse workers and assemblers	W	4	No sharp corners	Prototype
6.2	Ergonomics for mechanics	Easy disassembly and reassembly	W	1	Prototype	Product
7. Safety						
7.1	Not contain any harmful materials	No toxic chemicals	R		Check standards and regulations	Law
8. Aesthetics and finish						
8.1	Protective coating	Must be possible to cover with a protective layer	R		Check chemical combability	Material properties data
9. Quality and Reliability						
9.1	Corrosion resistance	High corrosion resistance in a corrosive environment	W	4		Product planning
10. Manufacturing						
10.1	Mass production	~100 000 pieces per year	R	4	Calculating upon design	Product planning
11.Packaging						
11.1	Stackable	Maximize number of parts per pallet	W	3	CAD and testing	Product planning
12. Operation						
12.1	Not fail under normal vibrations coming from the engine	Not fail under engine operation	R		Test	Current design
12.2	Provide suitable thermal expansion	For bolts to keep desired tension	R		Calculating	Product requirements
13. Maintenance						
13.1	No maintenance needed	Does not require any attention or service	W	4	Test	Current design
14. Recycling						
14.2	Easily recycled	Similar materials for eased recycling	W	3	Check standards for recycling	Product planning