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AN IDEA GENERATION METHOD FOR THE LATE PHASES OF ENGINEERING DESIGN

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Abstract

Creativity processes and idea generation techniques play an important role in innovation processes. They are necessary to get economic success. There are more than hundred techniques for creativity and problem solving. However, the space of techniques has been unstructured, and clear guidelines haven't been available for the selection of an appropriate technique for a given innovation goal. Idea Engineering provides an engineering approach to the problem of producing ideas.
We used methods of the approach of Idea Engineering and combined them with well-known evaluation methods from the field of engineering to evaluate these ideas. By using this approach we changed the design of a sealing of a universal joint of a powertrain shaft and reduced significantly the number of fails during the manufacturing process. The Idea Engineering approach was used in a late phase of the engineering design process.

Keywords: Creativity, Decision making, Design engineering, Evaluation, Idea Generation

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1 INTRODUCTION

Innovations are the key to get economic success. To be innovative, engineers need to get new ideas and have to be creative throughout the whole product development process. This process consists of being creative in the early stages, problem solving during development processes, and producing new products e.g. by using new manufacturing processes. Due to this fact the ability to be creative and to generate ideas is a key issue for an engineer. Additionally, this ability can be used to support the solving of all kinds of technical problems.

Unfortunately, the idea generation process in medium-sized and small companies is often unstructured and consequently ineffective, because on the one side engineers are not very familiar with creativity processes and on the other side creativity processes are generic and unstructured by themselves. Especially in regard to specific problems in the late phases of engineering design, creativity methods are not very common. Consequently a well-structured idea generation process with clear guidelines and supporting tools can improve results of engineering design.

We present an approach which has been designed to support the solving of specific engineering problems. It was developed and has been used in cooperation with IFA ROTORION - Powertrain GmbH and the Chair of Information Technologies in Mechanical Engineering (LMI). The objective was to improve an existing sealing of a universal joint of a powertrain shaft to avoid problems during the manufacturing process and to reduce the number of fails.

This paper is structured as follows. Firstly we present the motivation of the paper by describing the problem that had to be solved. Afterwards we explain creativity processes in engineering design by taking idea engineering into account and focussing on the structure of the idea generating group. We then describe the general process we developed on the bases of the previously presented research and demonstrate the applicability by using the sealing problem described above.

2 MOTIVATION

IFA ROTORION is a component supplier for the automotive industry and is specialised in drive shafts. An example of a two parted drive shaft with a universal joint highlighted is seen in Figure 1.

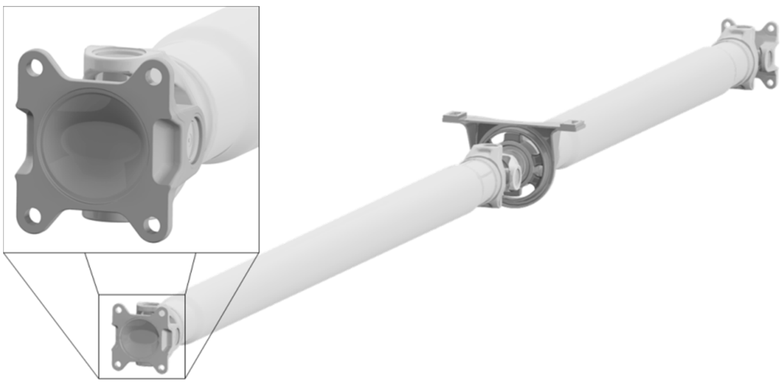

Figure 1. Drive shaft produced by IFA ROTORION

The problem to be tackled was a specific sealing element of specific drive shafts. The sealing in question is located at a universal joint to seal the needle bearing. The seal's material is of rubber with metal reinforcement. The seal has two sealing lips; one radial lip to prevent the lubricant of leaving the bearing, and one axial lip to protect the bearing from foreign matter (Figure 2).

A significant proportion of seals were damaged during assembly due to an inadvertent folding of the sealing lip. During the joining process the already assembled needle bearing is pressed by a press plunger on the corresponding pivot of the universal joint's spider. Depending on the joining machine, the concentricity of the opposite axes has a certain tolerance. Near the tolerance limits the sealing lip has to overcome a high shoulder to slide on the pivot. This leads in a high number of cases to the folding of the radial sealing lip resulting in the damage, seen in Figure 3. This defect can only be detected directly in the disassembled state.

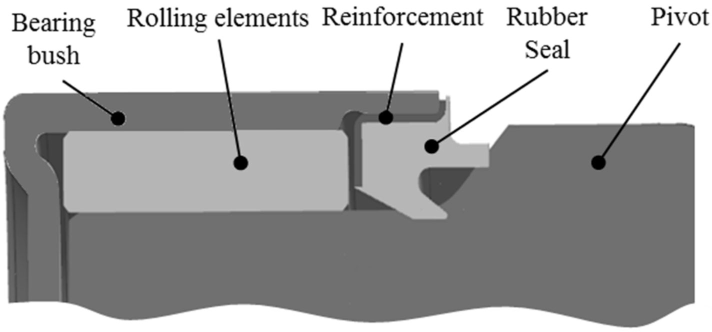

Figure 2. Cross section of the considered assembly

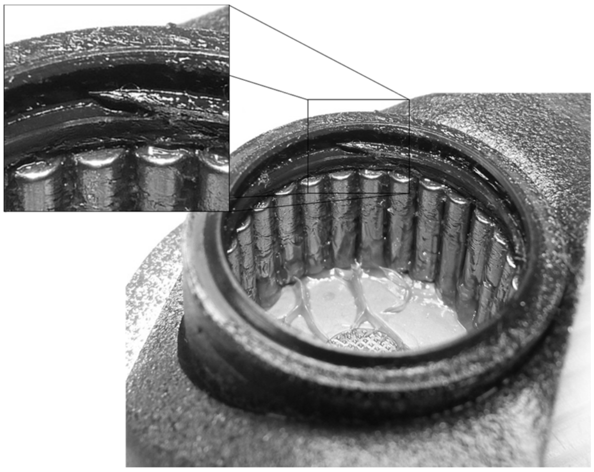

Figure 3. Sealing damage caused by folding

The task was to find solutions and ideas with which IFA ROTORION would be able to decrease the defection rate of this particular sealing significantly. However, the focus was not on finding one highly detailed solution rather than giving IFA ROTORION a lot of new, mediocre detailed ideas to work with. Therefore an idea generation process was used which enables the engineering group to achieve a high quantitative and qualitative productivity in idea generation.

The anticipated solution had to comply with constrains like the minimisation of costs by taking into account existing manufacturing facilities, processes, materials, etc. But of course these constrains could be softened when the benefits where predominating the efforts.

3 CREATIVITY PROCESSES IN ENGINEERING DESIGN

Creativity processes and idea generation techniques play an important role in the engineering design process. Often they are used in the early stages, the so called fuzzy front-end (Herstatt et al., 2004). Nevertheless, in later stages of the engineering design process creativity processes can be used very effectively. Many of the engineer's tasks in these stages are adaptive design and problem solving driven. We can say that creativity processes and idea generation techniques are needed during the whole engineering design process.

One of the most well-known techniques to generate ideas is brainstorming, which was introduced by Osborn as a method to improve the creativity of groups (Osborn, 1957). Nowadays more than one hundred idea generation techniques have been found and published, like the 6-3-5 Method, the Morphological Matrix, and the Random Input Method (VanGundy, A. B. 2005).

Most of the existing idea generation techniques are generic. The space of generation techniques has been unstructured. Clear guidelines for the selection of a given technique with regard to the innovation goal couldn't be found so far in literature. Due to this fact engineers and innovation managers have to rely on experience for the selection of an appropriate technique (Knoll et al., 2011). For this finding a large number of well-known creativity techniques were analysed in order to gain a theoretical understanding of the different routes by which ideas are generated. This analysis showed that there are essentially only six basic methods for creating ideas that can be described both simply and abstractly. This took the idea generation techniques to more an engineering approach, which is called Idea Engineering (Horton, 2006).

3.1 Idea Engineering

Because of generating ideas is a random process and depends on the different minds of different people, idea generation is expected to produce a large number of different raw ideas out of which the best ones have to be selected. Every engineer is an expert in his respective field and often he remembers solutions to known problems and adopts these to new situations and problems. This expertise is often a drawback when new solutions are needed because people are not able to free themselves of established thinking patterns, the so-called occupational blindness or tunnel (Horton, 2006). So, changing the perspective can help people to think "outside the box". Due to this reason the changing of the perspective will help to generate ideas in an easier way (Figure 4).

There are different strategies to provide stimuli for changing the perspective of individuals. One example can be called as the "Random Mr. X technique" or "What would Croesus do?" Mr. X or Croesus can be anybody e.g. Bill Gates or any company e.g. Google. Considering how Bill Gates would have solved the problem can result in new insights to the particular problem (Nalebuff, 2003). Knoll and Horton (2010) analyse these strategies and categorise them into three abstract cognitive principles:

- *Analogy* – Searching for situations akin to the corresponding creative task and using the knowledge of these situations to stimulate the idea generation process.
- *Provocation* – Questioning the status quo of the creative task to “force” the individual to overcome occupational blindness and to create a new perspective on the creative task.
- *Random* – Combining the features of the creative task with an unrelated item.

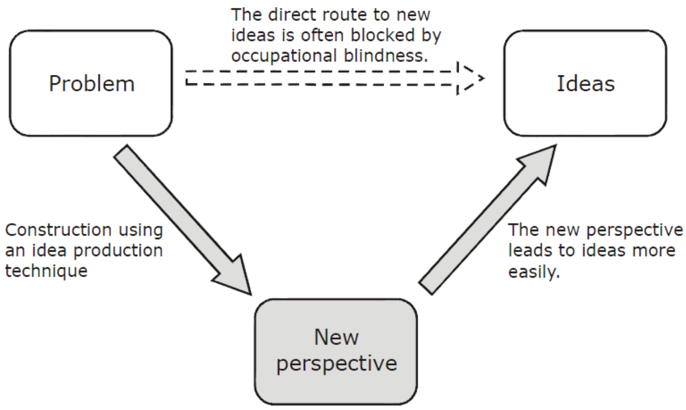

Figure 4. Changing the perspective can lead to new ideas in an easier way (Horton 2006)

The last important step is the evaluation of the large number of different raw ideas. The idea engineering approach needs for this stage a briefing that describes the customer’s problem, and goals, quality criteria, and boundary conditions.

The quality criteria are used to measure the success of an idea. Boundary conditions can be budget or time restrictions to implement an idea. The boundary conditions are used as quality controls. Every idea must pass through a filter which checks whether it satisfies the boundary conditions or not (Horton, 2006).

However, this evaluation approach doesn't seem to be very suitable for the particular problem and therefore, it was replaced by a more engineering-like approach. To evaluate the ideas, we used the standardised evaluation method proposed in VDI 2225 (VDI, 1998). This guideline was made by the Association of German Engineers (VDI – Verein Deutscher Ingenieure), that regularly edits guidelines to support engineers to their common professional activities. In many cases, these guidelines support or even become standards. The VDI 2225 proposes a simple approach, based on a five-points scale (0-4) to score the alternatives of an evaluation task. The criteria for this evaluation process were effort and benefit.

3.2 Idea Generating Groups

As past research shows the group structure is crucial for the success of the idea generation process. E.g. In the brainstorming approach first postulated by Osborn (1953) a team structure is used in which the members are working together at the same time and space. The goal is to build on others' ideas to generate more and better ideas. Since then the effectiveness of the team structure has been questioned. Major disadvantages, which are often cited, are production blocking, free riding, and evaluation apprehension. Production blocking describes the fact that only one person can speak in a team meeting (Kavadias and Summer, 2009). Emerging ideas from other participants might be forgotten while listening und understanding the speaker. One way that might mitigate this effect is the use of a trained facilitator (Offner et al., 1996, and Kavadias and Summer, 2006). Free riding occurs because members may feel that their effort is not needed or their effort is not enough appreciated when presented together with other ideas (Paulus and Yang, 2000). Evaluation apprehension hinders the idea generation productivity because members may not speak out their full idea because of the presence of peer evaluation.

Another group structure is the nominal group that keeps the group members isolated during the idea generation process. Mullen and Johnson (1991) show that nominal groups are significantly superior to the team structure of traditional brainstorming in regard to quantitative and qualitative productivity of idea generation. Their study suggests that the loss in productivity will be greatest

- when there is a relatively large number of participants,
- when the experimenter or some authoritative observer is present,
- when the participants have to express their ideas vocally rather than writing them down, and
- when the point of comparison is a nominal group of truly alone individuals.

A combined approach of the team structure of brainstorming and the individual aspects of nominal groups investigates Girotra (2010). In this hybrid structure there are times when the group members work individually and then work together. Girotra (2010) and others (Paulus et al. 1996, Stroebe and Diehl 1991) found that idea generation processes using the hybrid structure approach compared to the team structure lead to greater productivity. Furthermore, Girotra (2010) shows that the quality of the generated ideas is improved by using the quality of the best idea as the metric.

In order to increase the idea generation productivity both in regard to quality and quantity we use these results to structure our ideation process.

4 PROBLEM SOLVING BY USING CREATIVITY PROCESSES

The aforementioned theoretical bases were used to generate the creativity process. Herstatt's (2001) research indicates that sequential and formalized approaches are well-suited for incremental innovation. Therefore the idea generation process is structured into specific phases which are assigned to specific tasks. In the following sections, the general process is described and the implementation explained. It is to be noted, that the phases of the general process are only defined by the task and the outcome. How the phases are executed in terms of group structure, supporting tools, and working steps is adaptable. The above-described sealing problem serves as an example.

4.1 Description of the general idea generation process

The underlying cognitive principle of the chosen idea generation process is *provocation* (Knoll and Horton 2010). Since the task is a well described problem with detailed properties we choose the method for changing the perspective called "Upside-Down" or "Flipping". Here the engineer should consider solving issues the other way around and changing the properties of the particular problem (Horton, 2006, and Nalebuff et al., 2003).

Consequently the idea generation process starts with the analysis of the given system, problem, or task. The result of this step is a collection of properties describing the creative task. The following step is the upside down idea generation. Therefor every property gathered in the previous step is called into question to create a new perspective. This leads to new ideas that have to be evaluated in the next step. The separation of idea generation and evaluation is needed to optimise the group structure, in order to avoid evaluation apprehension (Diehl and Stroebe, 1987).

Based on the sheer amount of ideas an evaluation process with several loops is needed. With each loop the amount of ideas is reduced and the level of detail of the remaining ideas is increased. Not until the set of ideas is satisfactory, the process is finished (Figure 5).

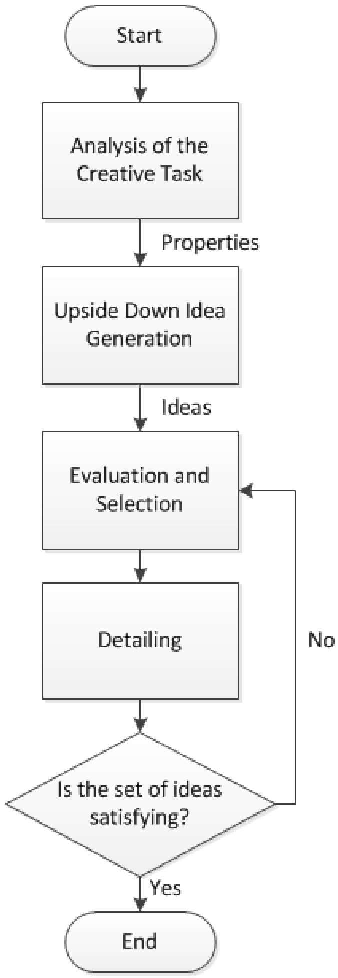

Figure 5. General idea generation process

4.2 Application of the general process on the given sealing problem

The first step was to analyse the respective system by just identifying the corresponding properties. Three engineers with different expertise did this in a one hour workshop. For this step the team structure was applied in order to avoid redundant work. In addition, the drawbacks of team work in brainstorming do not apply because Analysis of the creative task is simply the collection of facts with little creativity involved. In this approach we put the concerning system in the centre of the chart and arranged the identified properties around it (Figure 6). While we were doing this any comment of the mentioned properties regarding future solutions or usefulness of the corresponding property was forbidden. The result was not a detailed description of the sealing system but a collection of 28 describing properties. These properties are not only product specific, e.g. shape and material of the sealing, but also process-descriptive, e.g. manufacturing processes and assembly processes. Subsequently the obtained properties were placed in a table for further processing (Table 1).

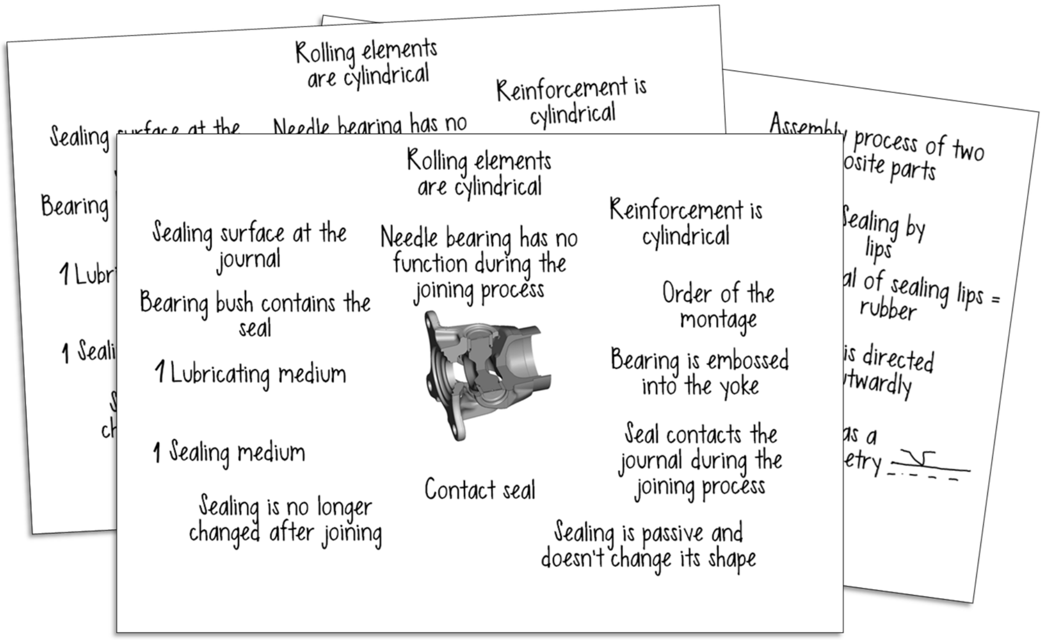

Figure 6. Resulting charts of the one hour workshop

To create new ideas we dissolved the development group and assigned every engineer a certain amount of properties, which he had to use to generate new ideas. This was done because of the above-mentioned results by Girotra et al (2010), Paulus et al. (1996), and Diehl and Stroebe (1991) that groups organised in the hybrid structure are able to create more ideas, better ideas, and to better discern the quality of the ideas than groups organised in teams.

In order to create ideas we flipped the generated properties upside down and put every aspect of the system into question. E.g. the initial system was using contact seals, so the corresponding idea was to install a non-contact seal. The thereupon-generated ideas were arranged again in the already existing table (Table 1).

The result was a great amount of rudimental ideas, which had to be evaluated in order to ensure an efficient detailing and developing of these ideas. So we applied an evaluation process consisting of two loops based on the general idea generation process illustrated in Figure 5. In the first loop we removed all nonsensical ideas, e.g. we discarded the idea to use more than one lubricating medium in contrast to the initial system that works with one lubricating medium. For this step of the loop, the three engineers worked together as a team to combine their different expertise to execute a well-grounded evaluation.

The next step was to separate the team again to benefit from the advantages of individual work and to avoid the negative impact of working together in the same time and space (Girotra et al., 2010). Then the remaining ideas were detailed by means of literature and patent research in order to prepare them for the second loop. Although the results obtained didn't need to have a high level of detail, they had to be precise enough to ensure a solid understanding of this idea by the other participants, so that an efficient additional exploration, further discussions, and the second evaluation could take place. In order to present the ideas properly they were visualised with simple drawings or explained in short literal descriptions. E.g. the idea to use a non-contact seal was detailed to the more precise idea that uses a labyrinth seal.

Table 1. Excerpt from the table used in the idea generation process

	What do we know?	Upside Down - Idea	Effort		Benefit		Sum of the rating
			Rating	Commentary	Rating	Commentary	
	Geometry System		4 – small effort 0 – too much effort		4 – great benefit 0 – no benefit		Effort + Benefit
1	Constant pivot diameter	Changing the pivot diameter	0		3		3
2	Geometry of the bearing bush is fix	Changing the geometry of the bearing bush	2		3		5
3	Needle bearing needs a minimum length of the pivot	Reducing the width of the needle bearing	3	Cannot yet be estimated	3		6
4	Needle bearing needs a minimum length of the pivot	Changing the length of the pivot	2		3		5
5	Needle bearing is used	Using another kind of bearing	1		2		3
6	Manufacturing tolerances are fix	Changing manufacturing tolerances	4		1		5
7	cylindrical shape of the journal / Brushes	Using conical bearing bush or pivot	1		2		3
8	Bearing bush is already assembled when stuck on the pivot	Mounting bearing bush partly assembled	1		1		2
9	Chamfer = 30° x 0,4mm	Changing the geometry of the chamfer	4		1		5
10	Axial guidance by bearing	Axial guidance by sealing surface	3		2	Cannot yet be estimated	5
11	Sealing surface is located on the journal	Shifting the sealing surface to the bearing bush	2		3		5
	[illegible] sealing	Separating the sealing from the bearing bush	[illegible]		[illegible]		5
	• • •						
41	Seal [illegible] process	[illegible]					
	In Use						
42	Small relative movement	Taking advantage of vibrations	2		1		3

The evaluation step of the second loop consisted of the already mentioned standardised VDI evaluation method (VDI, 1998). Due to the great number of ideas and the already small level of detail we used only two criteria for the evaluation process, i.e. effort and benefit. So we were able to filter promising ideas very fast and efficiently from the pool of ideas. Regarding the effort, an idea scored 0 points if its expected effort was too high for further exploration, and scored 4 points if its implementation would mean almost no effort for the company. In contrast, an idea scored 0 points in the benefit criteria if the expected outcome would achieve almost no positive effect in regards to the sealing problem, and scored 4 points if the idea would solve all aspects of the task (Table 1).

At the end of the evaluation we added up the scored points for each idea. Every idea with the sum of 5 or 6 was passed to the next phase of the solution process (Figure 5). In this phase the remaining ideas were further detailed by more intensive research, first CAD models, and detailed hand drawings. This was as well done in two steps. In the first step the detailing was made from each member individually, in the second step we finished the detailing by working together. The results of this step were 20 detailed ideas. An excerpt of the slides we used to present the remaining detailed ideas is shown in Figure 7.

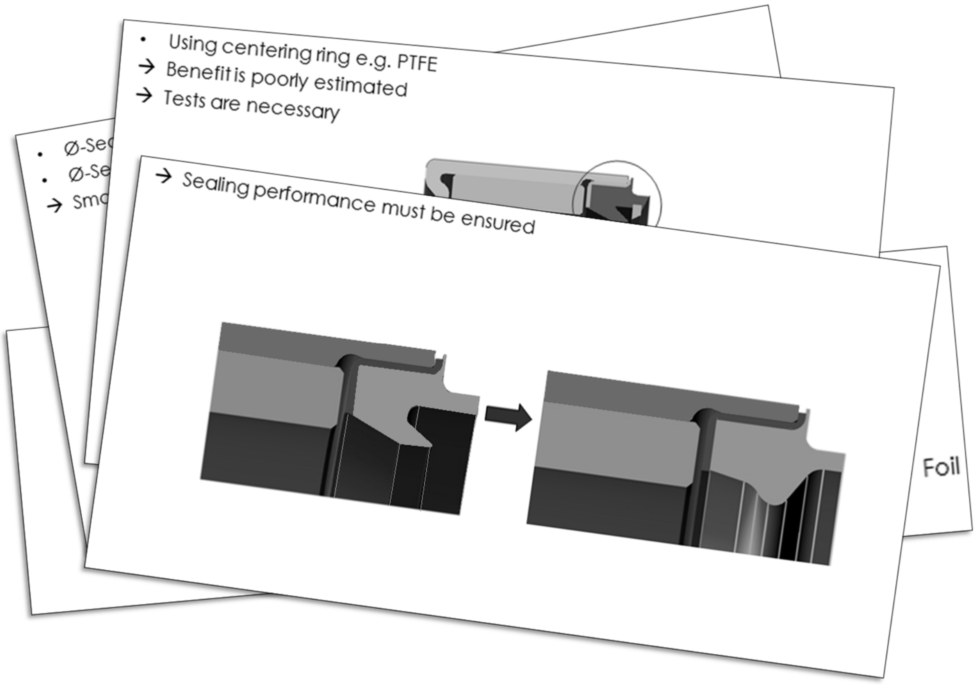

Figure 7. Slides used to present the detailed ideas

These ideas were handed over to IFA ROTORION for further exploration. The final solution was a combination of two of the detailed ideas. It consists of two radial sealing lips to prevent a lubricant leakage. It has a contact surface with two shoulders so the deformation of the sealing lips when they slide over the edge of the pivot is distinctly decreased. Furthermore, a protection cap is used to lower the chance of foreign matter to enter the bearing. With this system the defection rate of the defect could be significantly decreased.

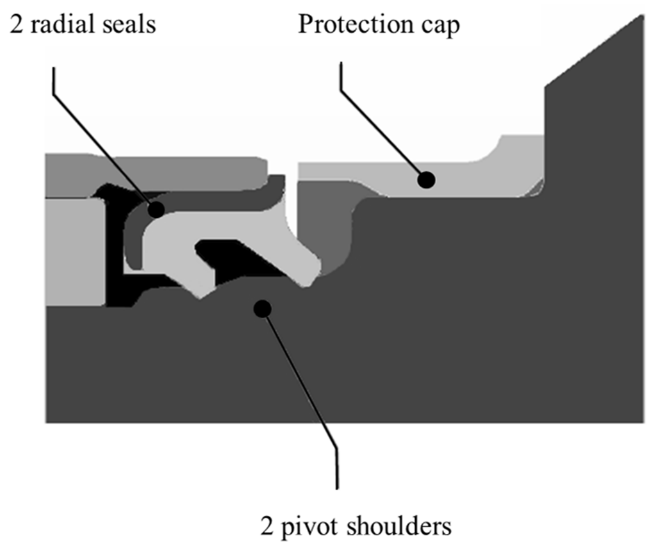

Figure 8. Final solution to the problem

5 CONCLUSIONS

Creativity processes and idea generation techniques play an important role in engineering design processes. Often these processes and techniques are used in the early stages of engineering design. We found that methods of the Idea Engineering approach can be combined with the standardised evaluation method proposed in VDI Guideline 2225 (VDI, 1998) to solve problems very efficiently also along the late phases of the engineering design process.

We validated this approach by changing the design of a sealing of a universal joint of a powertrain shaft. This action reduced the number of fails during the manufacturing process significantly. Based on the properties of the existing sealing system we generated ideas by flipping these properties. To evaluate these ideas, we used an evaluation process consisting of two loops in which the second loop was based on the already mentioned standardised evaluation process. The results of the process were structured and organised by the use of a table, which could serve as a template for similar future tasks.
We further found that it isn't necessary to do the whole process in continuous teamwork. Especially the generation of ideas by flipping can be done individually. But for the evaluation process of the ideas it is very useful to do this in teamwork because this stage needs a lot of discussions.
The advantages of this process are that this is both an engineering approach and a guided approach for solving problems by flipping the properties of a particular system or component. It is easy applicable to other problems in other stages of the product development process. Furthermore, this approach can generate a great number of ideas in a relatively short amount of time. So there is a high chance that with the right evaluation method one will find a good solution to a given problem. However, a weakness of this approach might be that it is hard to come up with new ideas that are completely separated from the initial properties of the system, because it is difficult to think "outside the box" if one has already a set of properties in mind. A further disadvantage could be the use of only two broad criteria "effort" and "benefit" in the second evaluation loop. It suited our needs and we achieved a satisfied result, but this particular approach can't be recommended for every case.
Further research could be done on validating the used idea generation method by comparing the presented method with other approaches. Therefore, it should be applied to a more general task. We suggest a validation based on the four variables that determine the best ideas proposed by Girotra (2010).

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