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13.1 CDMF-RELSUS concept: Reliable products are sustainable products - Automotive case study “clutch”

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Abstract

Based on the customer’s product recognition sustainability and environmental protection become key sales arguments within the automotive industry. Thereby customer expects reduced resource consumptions, environmental friendly manufacturing and optimised long usage phase. Especially product reliability saves resources in many ways. One main influence regarding to sustainable life span area of products is the design of a component during the design phase and the placing of upgrades during the use phase regarding to the balance of sustainability and reliability.

This paper outlines the “Collaborative development, manufacturing and field verification for higher product reliability towards sustainability (CDMF-RELSUS) concept”, substantiated by the automotive case study “clutch”. Based on a typical failure symptom of a clutch disk, the linkage of former field damage causes and prospective design stages is shown. With the aid of standardised innovation cycles inside the automotive industry an assignment between long-term sustainable manufacturing and reliability of mechanical components is demonstrated.

Keywords:

Life cycle Engineering, product reliability, sustainable design, manufacturing processes, field data analysis

1 INTRODUCTION

Sustainability and environmental protection become key sales arguments, especially within the automotive industry: Thereby the customer expects reduced resources consumptions, environmental friendly manufacturing, optimized usage and assortment of raw material and long customer usage phase (product reliability). In the opposite, the customer expects functionalities, innovations and modern equipment regarding to a new automobile. In summary the customer wants a product with a high quality for use. These requirements are all required by the customer. But in general, valid for all product branches, there are some preconditioned product characteristics, which none of the customers would directly express in a quantitative way: Reliability, quality and basic functions.

Manufacturer product reliability is associated with higher development and production costs, but, especially in industries with high innovation rates, customer usage is limited to the product actuality. Therefore there are two key questions with respect to this conflict area:

a. How much product reliability and, in addition, customer usage makes sense out of the view of manufacturers, customers and environmental protection?

b. What is the quantitative impact of reliable products regarding to the reduction of resources?

To increase the customer usage phase in innovative industries enhanced development strategies have to be implemented to ensure long customer usage, environmental protection and economical aspects. One strategy is the development of reliable (increase of product reliability) and upgradeable products. Through the upgrade capability additional functions or efficient components can be integrated or replaced over the customer usage phase, which leads to an extension (cf. Fig. 1) [1]. Precondition is an adjustment of the manufacturing planning regarding to the production of wear parts and remanufacturing possibilities with regard to the extended use phase. Finally, the verification of the product reliability - and therefore the sustainable product concept - can be based on field data.

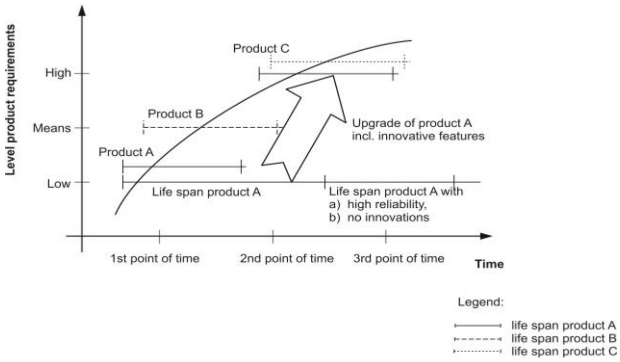

Figure 1: Level of customer´s product requirements versus successor development (Bracke, 1999)

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Therefore the main question regarding to future environmental products is: What are the influences and interactions of product development, manufacturing and use phase regarding to the focus "Reliable products are sustainable products" of this paper. This paper outlines the "Collaborative development, manufacturing and field verification for higher product reliability towards sustainability (CDMF-RELSUS) concept", substantiated by the automotive case study "clutch". Based on a typical failure symptom (wearout) of a clutch disk, a method for the linkage of former field damage causes and prospective design phases (design stages) is shown under the boundaries of a long use phase.

2 CDMF-RELSUS-concept: Goals

The focus of this paper is the main thesis "A reliable product is also a sustainable product from the ecological point of view."

With regard to the substantiation of this thesis, the main pros and cons are as follows:

Pro:

- A reliable product with a long useful life span area saves the following resources: Spare part production, spare part distribution, reuse of components (recycling), disposal of used parts, logistic efforts et cetera.

Con:

- A reliable product with a long useful life span area inhibits cycles of innovation with regard to their functionality and it inhibits clean technology regarding to the interaction with the environment during the use phase.

3 CDMF-RELSUS-concept: Base of operations

3.1 Overview and fundamentals

The "Collaborative development, manufacturing and field verification for higher product reliability towards sustainability (CDMF-RELSUS) concept" deals with three iterative points of view to evaluate a product regarding to the thesis "Reliable products are sustainable products". The three evaluation directions are as follows:

1. Impact of product design:
   Development of reliable products in contrast to product innovation cycles and reparability during use phase.
2. Impact of manufacturing planning:
   Analyse of machines/ facilities/ materials/ suppliers/ material flow during manufacturing (water, electricity, operating fluids, additives etc).
3. Impact of use phase:
   Verification of product reliability in the use phase; allowance of product recycling efforts regarding to the end of product´s life span area.

Before the main impact factors are substantiated in the following subsections, a more detailed overview will be mentioned.

The basic idea of the CDMF-RELSUS concept is the comparison of possible values which can be determined during the manufacturing planning and the use phase to support the decision making during the product life cycle. This assists to find an optimum solution for positioning innovation cycles (e.g. upgradeability) during the product life cycle with regard to the main goals of reliability and sustainability and the boundary conditions of a long use phase. The general process of this concept is shown in Figure 2, which combines on the one hand excerpt of the product life cycle and on the other hand the different innovation cycles (cf. Fig. 1). Each upgrade cycle λ is referred to an assembly i and its grade of upgrade k. Inside one upgrade cycle λ_(i;k) the product design phase deals with a number of assemblies i to z with an amount of components 1 to n. After the assembly is designed, the manufacturer plans the needed assembly, disassembly time and thus the proposed energy consumption for each assembly process i to z. Due to different perspectives, varied sustainability values val_(i;x) can be generated for each assembly process. After the products are delivered, the reliability of each assembly (e.g. component) i to z can be verified by state of the art methods (e.g. Eckel-method [18]) to determine the probability for upcoming defective assemblies val_(i;y). By building a linear or non-linear mathematical function of the values val_(i;x) and val_(i;y) the Relsus_factor_i can be obtained for each assembly.

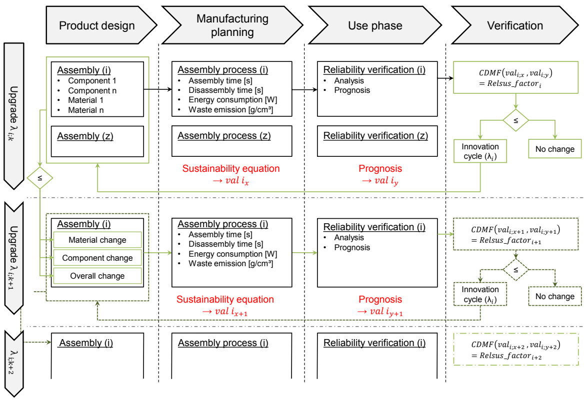

Figure 2: The CDMF-Relsus concept inside the product life cycle

The Relsus_factor_i can be a key element to specify a time-depending area for a strategic upgrade-cycle λ_(i;k+1) or not. If the decision leads to an upgrade-cycle, the former assembly i is renewed inside this cycle. With this significant assembly change by new materials or single components a new value val_(i;x+1) has to be determined in the manufacturing planning process. Afterwards the reliability of the assembly val_(i;y+1) has to be verified again, to examine the accomplished upgrade.

3.2 Assembly strategy optimisation due to innovation cycles (three construction stages)

This study introduces the case study of automotive clutch disk to focus on the innovation cycles. A clutch disk is used in an automotive transmission and is sandwiched in between the flywheel and the pressure plate. Figure A shows the schematic view of the clutch disk. This study focuses on the construction stages of a torsion spring of the clutch disk. There are coil springs located between the splined hub and the friction disc assembly. When the clutch is engaged, the pressure plate jams the friction facing against the spinning flywheel. The torsion springs compress and soften, as the friction facing first begins to turn with the flywheel. Through the movements of the expansion and contraction, the torsion spring absorbs some of the vibration and shock produced by clutch engagement.

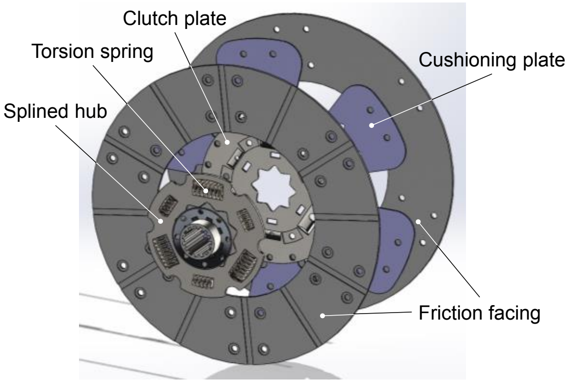

Figure 3: Schematic view of a clutch

The torsion springs are sometimes damaged due to fatigue breakdown. The case study has three construction stages: I, II, and III. The construction stages include the countermeasures such as the redesign of the splined hub and the torsion spring. Details of the improvements are different variants and combinations of materials and component geometries.

3.3 Determination of the assembly´s sustainability values

Automotive and most of their components are assembly products, where each part is assembled to become one product. In automotive manufacturing, it is known that the total number of parts is more than 30,000 items, all parts are gathered by procurement from suppliers in supply chains bridged among suppliers, manufacturers and customers, and their final assembly by a manufacturer is often carried out at assembly line systems (ALS) [13]. The ALS is a traditional production system established as a Ford production, and basically consists of serial production stations connected by conveyors. This system is superior in the efficiency for flow of materials/ units because the work stations are connected by material handlings such as conveyors [8].

Two main economical aspect of the assembly line is assembly time and line balancing [8]. Most of assembly works are still done manually by human operators since the works are complex and should be flexible. The reduction of the assembly time by product design and work improvement contributes to reduce the labour costs. Also, the line balancing is to assign each elemental assembly task to each workstation/ operator with a division of labour, and the balance loss inevitably occurs at the line production. When the line has a good balance, it contributes to reduce the number of and cost of the facilities/ operators.

With regard to sustainability for these assembly products by manufacturing, three environmental issues mainly are: global warming, material circulation and biodiversity [14]. Global warming is the phenomenon by which the world average temperature rises due to the rising concentrations of GHGs, particularly CO2. Materials of each part must put out CO2 by mining, manufacturing and logistics, therefore, the low-carbon supply chain should be constructed, where their CO2 emissions should be visualized and reduced along the entire supply chain because products are manufactured by more than one process or enterprise [14]. By using life cycle inventory data bases, the CO2 volumes of each part can be estimated (for example, [15]).

On the other hand, the material circulation is also required because natural resources such as materials and energy are scarce, and waste becomes more serious. To promote material circulation and reduce the generation of wastes, reuse and recycling should be promoted by closed-loop supply chain [16] which is consisted of regular and reverse supply chains with disassembly [17].

When a more reliable part/ component are introduced for sustainable products, the mentioned economic and environmental aspects are quantitatively evaluated in advance for the whole product lifecycle. Therefore, they are still design challenges how to evaluate the economic and environmental aspects in advance, and how to harmonise the economic and environmental objective by product design and production management after the evaluation.

3.4 Determination and analysis of the assembly´s failure occurrence

A general procedure to verify the reliability of an assembly due to a known failure mode is the analysis of the failure behaviour after a certain usage time and thus the determination of upcoming damaged assemblies by using various prognosis methods. Inside this paper each innovation cycle (e.g. construction stage) has been analysed after six months in service (MIS). Furthermore the prognosis has been evaluated under the usage of the Eckel-method [18].

Figure 4 shows the different analyses due to a changing failure mode of the first to third failure occurrence regarding to the construction stages and manufacturing influences. The first manufactured assemblies lead to a failure rate of ‘X’ % after 6 MIS, whereas the second construction stage leads to much lower failure rate of nearly ‘Y’ %. Furthermore it can be seen that the failure mode itself changed. The highest documented failure occurrence is inside the second construction stage at ‘Z’ km and the failure mode seems now to be dominant at ‘Z2’ km. A main influence on this change between both failure modes can be seen as an assignment of a new material.

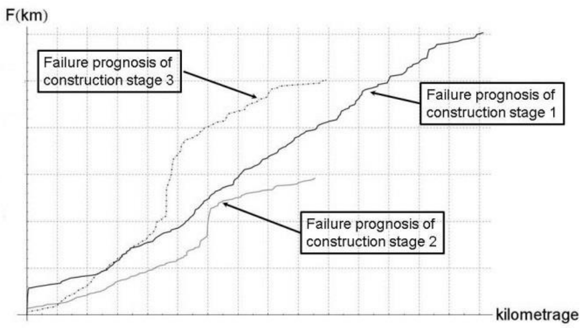

Figure 4: Risk analyses after six months in service of each innovation cycle

The last construction stage which has been analysed shows comparable failure behaviour but leads to higher expected amount of upcoming failure assemblies of nearby ‘Z’ %.

With the given characteristics (material selection, waste pollution and failure rate) the need of a close innovation cycle reflecting all influences should be obtained and is discussed in the following section to verify the methods attempt regarding reliable and sustainable assemblies.

4 VERIFICATION CDMF-RELSUS: APPROACH WITH REGARD TO CASE STUDY CLUTCH

The verification of the iterative CDMF-RELSUS concept is shown inside this paper after the third innovation cycle/ construction stage.

Figure 4 illustrates the given boundaries after the third established innovation cycles. Thus the figure shows the amount of reliable assemblies after 18 month in service, the needed manufacturing energy per assembly and the wasted emissions per assembly in space. In addition a function has been fitted by using a general polynomial of second order to substantiate relationship between the characteristics.

With these given characteristics (e.g. fitted function), various optimisation methods [9] can be obtained to generate a nearby optimal solution between the acceptable failure occurrence and the maximum acceptable investigated energy to still maintain a required critical value of waste pollution, for example.

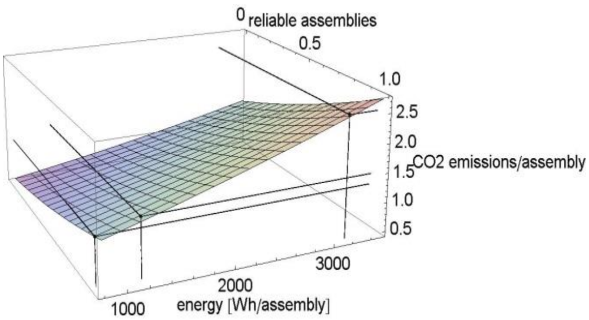

Figure 5: Determination of the Relsus_factor_3 to verify an optimised innovation cycle 4

Inside this paper the transposed characteristics (simulated data and exemplary units) after the third innovation cycle of the clutch disk are shown in Table 1.

Table 1: Simulated data to generate the RELSUS_factor after the third innovation cycle

	Maximum failure occurrence [%]	Energy [Wh]	CO_2 emissions per assembly [g/cm³]
Minimum value		2000	1.011
PV	3.5	2150	1.094
Maximum value		2200	1.123

The maintained critical value of waste pollution should be smaller than 1.1 g/cm³ of CO2. With the given boundaries manufacturing the clutch disk within an amount of 2000 – 2200 Wh and a maximum acceptable failure rate of 3.5 % various possible values of waste pollution that fulfil the requirements (PV) can be calculated.

Therefore the fitted function leads to a possible value of 1.094 g/cm³ if the given failure occurrence of 3.5 % can still be justified by applying an investigated energy of 2150 Wh.

5 CONCLUSION

The “Collaborative development, manufacturing and field verification for higher product reliability towards sustainability (CDMF-RELSUS) concept” shows aspects, influences and strategies to substantiate the thesis “A reliable product is also a sustainable product from the ecological point of view.” It shows the complexity and the interdependences of the three main impacts product design, manufacturing planning and use phase. The CDMF-RELSUS concept is a first base of operations for the development of a successor model, which combines the characteristics of sustainability and reliability.

This paper shows a method to combine different values to appraise future decisions to obtain an optimal innovation cycle. Under usage of such a new implemented construction stage the aspects of sustainability and reliability are considered more precise. Methods of the CDMF-RELSUS-concept were demonstrated within the automotive case study “clutch”. Furthermore, an approach for verification of the fundamental CDMF-RELSUS iteration process is shown with regard to three clutch innovation cycles are shown.

Future research work will contain checklists and criterions, which help the design engineer to consider the combination of sustainability and reliability with regard to the product construction and manufacturing. Furthermore, case studies and design examples will be adopted more precise to validate the proposed concept of this paper. Inside future case studies different mathematical functions will be applied to verify the disparity in describing the characteristics relationships.

Based on full CDMF-RELSUS concept and the case study, a guideline will be developed, how to consider verified product reliability based on field data in the successor development. Finally, the CDMF-RELSUS concept considers the interaction of the intended end of the product´s life cycle (product recycling or material recycling) regarding to the environment.

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