# RELIABILITY ESTIMATION IN PRODUCT CONFIGURATION ISSUE

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Summary

In the product configuration problem of mechanical product type reliability is one of the most important requirements. Product adjustment to customer expectations, which mean product customization, decides about its commercial success. Development of methods helpful in the early phase of product design is needed to product customization. The early phase of design problems is focused on deriving the optimal solution that satisfies some objective functions like e.g. reliability. The proposed product decomposition method and system reliability estimation were presented.

Keywords: product decomposition, reliability estimation.

SZACOWANIE NIEZAWODNOŚCI W ZARZĄDZANIU KONFIGURACJĄ PRODUKTU

Streszczenie

W problematyce zarządzania konfiguracją produktu przemysłowego niezawodność jest jednym z podstawowych wymagań. Dostosowanie produktu do wymagań klienta, czyli kustomizacja decyduje o sukcesie rynkowym. Rozwój metod wspomagających wczesne etapy projektowania produktu jest niezbędny do jego kustomizacji. Wczesne fazy projektowania produktu wymagają prowadzenia optymalizacji z uwzględnieniem niezawodności jako funkcji celu. W artykule przedstawiono proponowaną metodę dekompozycji produktu oraz szacowania jego niezawodności.

Słowa kluczowe: dekompozycja wyrobu, szacowanie niezawodności.

## 1. INTRODUCTION

Product customization needs a configuration algorithm, which assures customer satisfaction. The configuration algorithm can use the existing, well known components or redesign them. So, in many cases the core product is the same, designers redesign some product components to fulfill given customer requirements. The question is how to estimate reliability for a modernized product.

One of the most important problems in the product configuration issue is product decomposition which provides a combination of components which give product suitable for a particular client. Product decomposition and functional requirements will help to answer the following question: Which physical element(s) is responsible for the fulfillment of a specific functional requirement? [5]. In literature we can find different approaches to product decomposition [2], [3].

The proposed idea of product decomposition includes three levels of classification attributes and their values. The first classification level includes products portfolio (product line), their attributes and their values, where each product line is characterized by a set of similar product structures (e.g. helical reducers) which use particular parts' set.

Finding the optimal product profile from a product family for a particular customer is an optimization problem which includes the problem of process modeling related to translating customer requirements into engineering characteristics. One of important goals of configuration algorithm is assure product reliability.

The objective of this paper is to present results of research on modernized product reliability estimation.

## 2. PRODUCT RELIABILITY DECOMPOSITION

Quality is a property which may change with the age of the product[4]. Customer product acceptability will depend on its reliability, that's mean ability to continue to function satisfactorily over a period of time. Reliability is one of the most important aspects of competitiveness, so in product development it is necessary to take into consideration reliability during product and process design. Designers have to assure product reliability by using [4]: proven designs, the simplest possible design, components of known or likely high probability of survival, employ redundant parts, design to "fail-safe", specify proven operations and methods.

In product and process design it is necessary to predict possible failures and their effects to increase product reliability. Failures could be caused by different features e.g.: wrong design, material, process, operation. In failure analysis it is necessary to take into consideration experiences from service, technology, design, suppliers and customers. Identification of the failure cause is a key point in decreasing potential problems.

The study of time-variant structural system reliability is still developing. In order to perform a realistic reliability analysis of a structural system, the best approach is to find the probability of system failure over a period of time t [1].

Different reliability measures existed in literature. Reliability which is time dependent R(t) may be calculated as number surviving at time t and number existing at t=0 quotient, or based on cumulative distribution of failure calculated as 1-R(t) or based on probability density function of failure, or failure or hazard rate or mean time between failures.

Reliability system may be considered to be of two kinds: a series system in which failure of either components causes failure of the whole system, and a parallel system where components operate in parallel.

In product reliability estimation reliability decomposition (allocation) is an important issue. Reliability allocation is understood as the process of assigning reliability requirements to individual components or sub-systems to attain the specified system reliability [5].

To create reliability model it is necessary to achieve a specified reliability goal for the system.

According to [5] most of mechanical systems are designed in a series system, so the series system reliability $R_s(t)$, assuming that the failure of any function $i$, component $j$ and failure mechanism $k$ will lead to system failure, could be estimated basing on:

$$R_s(t) = \prod_{i=1}^{p}\left[\prod_{j=1}^{q}\left\{\prod_{k=1}^{m} R_{ijk}(t)\right\}\right] \quad (1)$$

$$R_s(t) = \exp(-\lambda_{t_s} t^{\beta}) \quad (2)$$

$$R_{ijk}(t) = \exp(-\lambda_{t_{ijk}} t^{\beta}) \text{ for } t \geq 0 \quad (3)$$

$$\lambda_{t_s} = \sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{m} \lambda_{t_{ijk}} \quad (4)$$

$$\theta_s = \left\{\sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{m} \frac{1}{\theta_{ijk}^{\beta}}\right\}^{-\left(\frac{1}{\beta}\right)} \quad (5)$$

$$\lambda(t) = \beta\left(\frac{t^{\beta-1}}{\theta_{111}^{\beta}}\right) + \ldots + \beta\left(\frac{t^{\beta-1}}{\theta_{111}^{\beta}}\right) = \beta\left(\frac{t^{\beta-1}}{\theta_{s}^{\beta}}\right) \quad (6)$$

Where:

$\lambda(t)$ - The system hazard rate at any time $t$;
$\lambda_{ts}$ - The transformed failure rate of the system;
$R_{ijk}(t)$ - Reliability of $k$th failure mode for $i$th function and $j$th component for mission time $t$;
$\theta_s$- Life of the system;
$\beta$ - Shape factor.

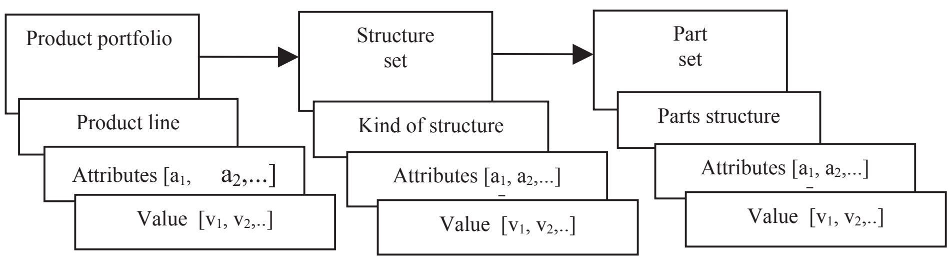


Fig. 1. The idea of product decomposition

## 3. TOOTHED GEAR EXAMPLE OF PRODUCT RELIABILITY ESTIMATION

### 3.1. Problem formalization

Producers of machine elements like e.g. toothed gear, besides product portfolio presented in catalogues offer to their clients product adaptation, which means product customization. The goal is to create reliability estimation model which helps in product configuration according to particular customer expectations.

Configuration design is focused on establishing the product based on the pre defined parts' set and could be divided into classes: the first includes pure composition in which a set of parts is already known; in the second class parts could be redesigned in case suitable parts cannot be found. In the presented approach reliability estimation can be based on product decomposition presented in fig. 1. and the decomposition of system level reliability described on p. 2.

### 3.2. Failure probability estimation

According to the proposed product decomposition method, reliability analysis can be based on reliability matrix (fig.2). For each product decomposition level attributes and a set of values were established. Each product line is characterized by attributes and their values like, e.g. geared motors could be characterized by horizontal and vertical working arrangement, product structures are divided into different kinds which are also characterized by attributes and their values, e.g. double reduction number. A Set of parts includes information like, e.g. nominal modules in toothed elements used in particular kind of product structure. For parts' sets the failure mechanism is specified and estimation of failures could be made. Based on reliability matrix, probability of failure could be estimated on the basis of regression analysis. An example related to toothed elements production process was shown on the fig. 3.

| | | | | | | | | | Failure mechanism | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Product line | Attributes | Value | Kind of structure | Attributes | Value | Subsystem / Component reliability | Attributes | Value | Transportation failure | Processes failure | Supplier cause failure | Fatigue failure | Construction failure | Unidentified | Wrong selection | Reliability | |
| Geared motors | working arrangement | Vertical | Helical | Reduction number | Double triple quadruple quintuple | Bearings | Type | | 1 | 1 | 0,989 | 0,997 | 1 | 1 | 0,989 | 0,975 | 0,818 |
| | | | | | | Housings | Type | | 0,998 | 0,999 | 0,979 | 1 | 0,999 | 1 | 0,998 | 0,973 | |
| | | | | | | Toothed elements | Module | | 1 | 0,998 | 0,997 | 0,999 | 1 | 1 | 0,969 | 0,963 | |
| | | | | | | Shafts | Length / diameter | | 1 | 0,999 | 0,999 | 0,997 | 1 | 1 | 0,969 | 0,964 | |
| | | | | | | Packing | Type | | 1 | 1 | 0,989 | 1 | 1 | 1 | 0,969 | 0,958 | |
| | | | | | | Lubrication | Type | | 1 | 1 | 0,999 | 1 | 1 | 1 | 0,969 | 0,968 | |
| | | | Bevel – helical | Reduction number | Double triple quadruple quintuple | Bearings | Type | | 1 | 1 | 0,999 | 0,997 | 1 | 1 | 0,989 | 0,985 | 0,842 |
| | | | | | | Housings | Type | | 0,998 | 0,999 | 0,998 | 1 | 0,999 | 1 | 0,998 | 0,992 | |
| | | | | | | Toothed elements | Module | | 1 | 0,998 | 0,997 | 0,999 | 1 | 1 | 0,969 | 0,963 | |
| | | | | | | Shafts | Length / diameter | | 1 | 0,999 | 0,999 | 0,998 | 1 | 1 | 0,969 | 0,965 | |
| | | | | | | Packing | Type | | 1 | 1 | 0,988 | 1 | 1 | 1 | 0,969 | 0,957 | |
| | | | | | | Lubrication | Type | | 1 | 1 | 0,999 | 1 | 1 | 1 | 0,969 | 0,968 | |
| | | Horizontal | Helical | Reduction number | Double triple quadruple quintuple | Bearings | Type | | 1 | 1 | 0,989 | 0,997 | 1 | 1 | 0,989 | 0,975 | 0,843 |
| | | | | | | Housings | Type | | 0,998 | 0,999 | 0,999 | 1 | 0,999 | 1 | 0,998 | 0,993 | |
| | | | | | | Toothed elements | Module | | 1 | 0,998 | 0,997 | 0,999 | 1 | 1 | 0,969 | 0,963 | |
| | | | | | | Shafts | Length / diameter | | 1 | 0,999 | 0,999 | 0,997 | 1 | 1 | 0,969 | 0,964 | |
| | | | | | | Packing | Type | | 1 | 1 | 0,999 | 1 | 1 | 1 | 0,969 | 0,968 | |
| | | | | | | Lubrication | Type | | 1 | 1 | 0,999 | 1 | 1 | 1 | 0,969 | 0,968 | |
| | | | Bevel – helical | Reduction number | Double triple quadruple quintuple | Bearings | Type | | 0,998 | 0,999 | 0,979 | 1 | 0,999 | 1 | 0,998 | 0,973 | 0,818 |
| | | | | | | Housings | Type | | 1 | 0,998 | 0,997 | 0,999 | 1 | 1 | 0,969 | 0,963 | |
| | | | | | | Toothed elements | Module | | 1 | 0,999 | 0,999 | 0,997 | 1 | 1 | 0,969 | 0,964 | |
| | | | | | | Shafts | Length / diameter | | 1 | 1 | 0,989 | 1 | 1 | 1 | 0,969 | 0,958 | |
| | | | | | | Packing | Type | | 1 | 1 | 0,999 | 1 | 1 | 1 | 0,969 | 0,968 | |
| | | | | | | Lubrication | Type | | 0,998 | 0,999 | 0,979 | 1 | 0,999 | 1 | 0,998 | 0,973 | |

Fig. 2. Reliability matrix

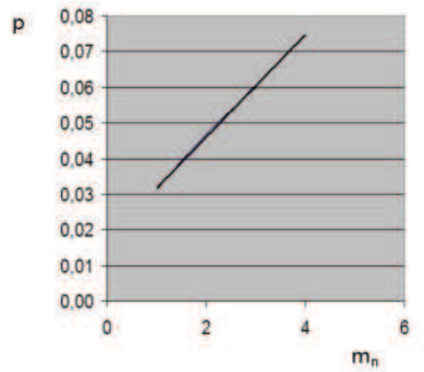


Fig. 3. Estimation of process probability failure (toothed element processing according to Reishauer method)

Nominal module was taken as toothed element attribute. Basing on nominal module, the failure probability of toothed elements processed according to Reishauer method was estimated.

In the Reishauer method a high degree of machine wear affects higher failure rate - the greater cutting resistance, the more likely failures are.

## 4. CONCLUSION

It is necessary to develop methods useful in product customization, which are helpful in product configuration suitable for a particular client. One of the most important problems in product configuration issue is product decomposition, which provides a combination of components which gives product suitable for a particular client.

The proposed idea of product decomposition is useful is product reliability estimation. The proposed approach joins problems related to product decomposition widely discussed in literature [2], [3] with those related to product configuration issue and theory of reliability [4], [5]. The proposed approach is applicable in mechanical product type and is a useful tool for creating the optimal product configuration. Numerical data used in reliability matrix could be taken from FMEA analysis, complaints analysis or quality assures system.

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