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SELECTION OF PHYSICAL EFFECTS BASED ON DISTURBANCES AND ROBUSTNESS RATIOS IN THE EARLY PHASES OF ROBUST DESIGN

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ABSTRACT

Within this paper products are called robust, if uncertainties (property variations and disturbances) from production and use have no or little influence on the result during the use. In order to design products robust from the beginning of the design process, their design is to be carried out in a methodically supported Robust Design process (RD). Therefore, one has to be able to examine robustness already during the concept design.

In order to support the concept design of the RD methodically, a catalog is developed here, in which the influencing disturbances are assigned to the single effects.

Furthermore, three robustness ratios are defined. These are R_I (disturbance based robustness ratio), R_{II} (environment dependent robustness ratio) and R_{III} (sensitivity dependent robustness ratio). It is the goal of these ratios to enable a selection of physical effects with the help of their robustness based on different amounts of information and effort within the early design phases.

An exemplary appliance of the catalog and the ratios is carried out with the help of the design of a wrist watch.

Keywords: Robust Design, physical effects, robustness ratio, disturbance

1 INTRODUCTION

In many cases new products fulfil the expectations of the customers insufficiently or not at all during the use. This can partially be ascribed to variations occurring in the production. These variations can cause property variations of the products. Now, inaccuracies or excessive wear can lead to a not satisfying result during the use.

However, it occurs more often that the customer uses the product in a way, which was not intended during the design. Mostly, the result does not meet the expectations of the customer. Particularly, if the not intended use is carried out unknowingly, the customer will blame the product for the insufficient result. Therefore, the customer will be dissatisfied with the product.

Regarding the use of the product in a new environment, it is even more critical. Mostly, a number of different disturbances affect the product within the environment. These disturbances mostly influence the result seriously. However, the customer mostly will not take these disturbances into consideration. He often takes it for granted, that the product can be used in any environment and meets his expectations. Therefore, a not satisfying result is due to a bad product.

Variations regarding both properties and disturbances, causing the phenomena described above, can be summed up as uncertainties. If one wants to design a product, which completely satisfies the customer during the use, the result during the use has to meet the expectations of the customer despite these uncertainties. Thus, the product has to be designed in such a way, so that uncertainties cannot affect the result within the use.

In the following, a product is called robust, if uncertainties do either not or insignificantly affect its behaviour and therefore the result in the use.

A typical measure in order to control uncertainties in particular is the limiting of the application range concerning certain environment quantities. For example, the temperature range, in which an appliance can occur, is limited for many products. By this, an examination of this disturbance becomes unnecessary for the product design in a large extend. However, it is obvious, that such a measure is not to be preferred. On the one hand, the product design cannot exclude the fact, that the customer still uses the product outside the range leading to problematic results. On the other hand, the application

area of the product can be reduced significantly. If competitive products can be used without limitations, a limitation of the potential market is provoked.
If one does not want to consider limitations as the only measure, it is necessary to design the product robust. However, in this case a larger number of uncertainties has to be considered. Therefore, it is essential to execute a robust design in a systematic Robust Design process (RD) [1]. The RD possesses the greatest potential, if the uncertainties are examined elaborately from the beginning of the design. Thus, the RD qualifies especially for the systematic new product design. In this case, one has to be able to consider uncertainties in the used models already in the early phases. Furthermore, a selection of different solution possibilities based on robustness has to be executable. One basic product model in the early phases is the model of physical effects. In this paper, an approach is going to be presented how to examine uncertainties in form of disturbances regarding physical effects and how to evaluate the individual effects by using robustness ratios. In the end, the purpose of the robustness ratios is to serve for the selection of the physical effects.

2 INTRODUCTION INTO THE USED EXAMPLE OF A WATCH DESIGN

For a better understanding, the design of a watch is used as a demonstrative example in the following. Basically, the functions and the structure of a watch are very simple. This is already shown by the function structure (Figure 1). First energy need to be stored inside the watch to enable the following functions. The main function give pulse is based on an external time signal. Often the signal needs to be changed inside. The function show time then transfers the internal signal into the output optical signal that can be interpreted by the user and be used to get the information about the actual time.

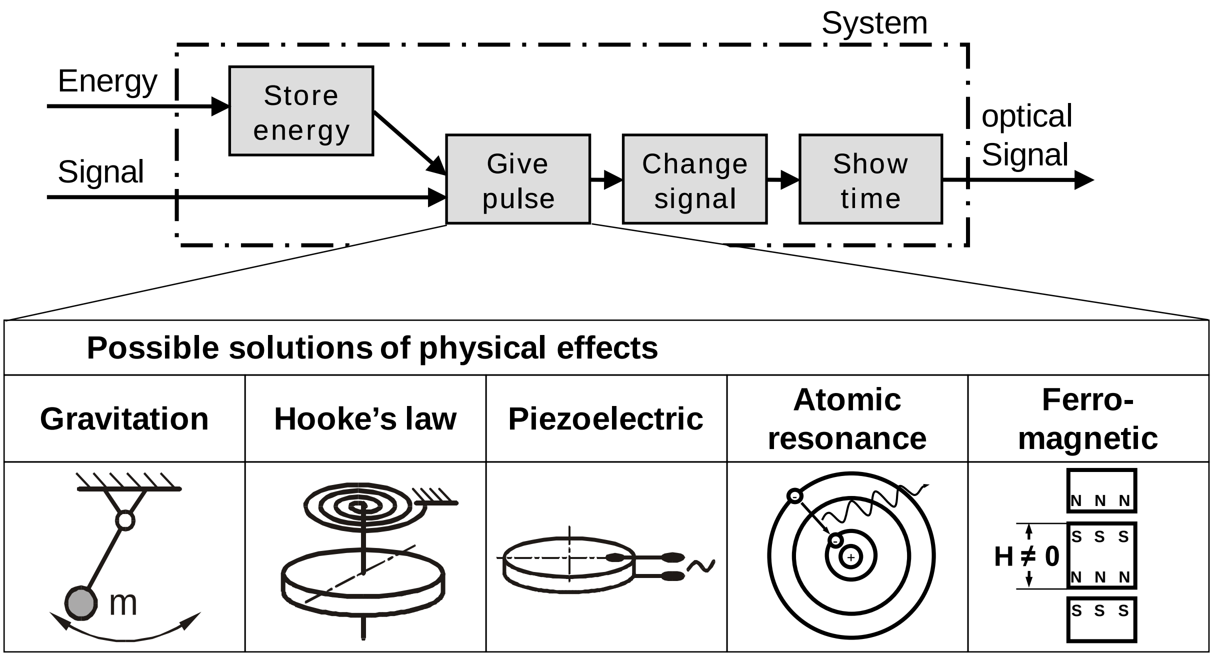


Figure 1. Function structure of a watch and solution possibilities for the sub-function give pulse on the level of physical effects

Furthermore, the individual sub-functions of a watch can be solved well by using physical effects. The sub-function give pulse can be solved by completely different physical effects. For example, long cases clocks use gravitation in order to carry out give pulse. Mechanical wrist watches use the hooke`s law when containing a spiral spring. The piezoelectric effect is used in quartz clocks. Atomic clocks use the atomic resonance. Furthermore, the ferromagnetic effect is applied within the concept development Pendulum of the company TagHeuer [2].
In the following, only the sub-function give pulse and the effects described above are examined. In future research, the examination is going to be expanded by taking the generation of combinations of the sub-functions in form of a morphological system into consideration.

3 DEVELOPMENT OF A CATALOG FOR PHYSICAL EFFECTS COMBINED WITH DISTURBANCES

Science provides a large number of information within the field of physical effects. Catalogs can be used in order to store and offer this information in a convenient way [3, 4].

If one analyses the existing catalogs [4, 5, 6, and 8] in regard to the consideration of disturbances, one notices that there is no systematic examination. However, one finds some scattered hints to disturbances. For example, Koller [4] writes in context of the effect natural frequency/ eigenfrequency (quartz): “The eigenfrequency of oscillating quartz changes with temperature depending on the direction of the cut”. Thus, temperature can be seen as a disturbance indirectly with reference to the piezoelectric effect. A direct hint to the possibility of acquiring disturbances and of storing them in catalogs is given by Presse [9] in 1977. “In a planned collaboration with physicists perturbations and technical efforts are to be registered, so that the catalog can be offered in a more meaningful way.” However, after an extensive inquiry, one ascertains the fact that this approach has not been followed up and that there is no catalog of physical effects combined with disturbances up to now.

Basically, disturbances and their related information can be compiled easily in form of lists. Since now the effects are to be examined in regard to their disturbances, it is expedient to integrate these lists in a catalog. Thus, a structure of a comprehensive catalog has to be developed accordingly.

A paper-based version of the catalog is not expedient. One reason is the large extent of the new catalog. As one notices in 3.2, the examination of a single effect with its disturbances quickly becomes largely extensive. Since the catalog is extended by the element “disturbance”, the catalog becomes significantly more extensive than present catalogs. Another problem is the access. When comparing the different ways to access the effects, one notices that it is the access using disturbances which provides many possibilities of use. This kind of use is not effective when using a paper-based form even if one uses an access based on solution characteristics according to Roth [7, 8, and 3]. Therefore, it is necessary to provide the catalogs in the form of a computer application using databases.

Now, a critical examination of the existing catalogs in regard to their present content and structure is going to be executed. Afterwards, a basic catalog is going to be defined in order to provide an adequate basis for the development of a computer-based comprehensive catalog of physical effects with their affecting disturbances.

3.1 Basic configuration and content of a catalog for use in RD

The developing of the contents of catalogs has especially been expedited by Koller [4] and Roth [7, 8]. Their catalogs still represent the current state of research with regards to content.

If one observes the catalogs of Koller in connection with current literature about physical effects, it becomes obvious that today more physical effects are applied in products than there are currently listed. The catalogs according to Koller, in which physical effects are described, consist of about 220 effects. In von Ardenne [10] the use of about 280 effects in 345 articles is described elaborately and their applications are presented. However, it is focused on effects which are suitable for applications, although the “selection of the covered effects certainly is subjective and not complete at all” [10]. However, often new/unknown effects can be used in the context of new product design, in order not to be influenced by known solutions. Here, new/unknown effects often provoke new ideas and thus directly or indirectly lead to successful innovations. Therefore, with regards to content it is expedient to build up a catalog on the basis of the catalogs according to Koller and Roth during constant revising and completion supported by current literature.

Koller uses an assignment matrix for the purpose of access to the effects of the catalogue. Within this matrix, the effects are classified according to their cause and impact. Due to this classification system and the paper-based realization, many effects appear several times within the catalog. The catalog becomes largely extensive. In addition, the use of the catalog requires some acquirement and experience of the engineer.

The catalogs according to Koller and Roth are also referred to within current literature of product design and are used for the development of own catalogs. These catalogs often reduce the content in order to improve clearness. Ehrlenspiel [6] reduces the catalog to a number of 169 elements. Here, the mathematical-physical descriptiveness possesses a major role for the simplification of the assignment matrix. In this assignment matrix 20 physical quantities are listed against each other. Furthermore, many effects are listed multiple times in the catalog. Examining Ponn [5], one notices that there are no multiple effect descriptions due to the simplified configuration of the assignment matrix. The number of examined covered effects is 87. In addition, nowadays the simplified catalogs reduce the contained information to the most important elements which are necessary for a general overview of the effects. The realization as paper-based lists is decisive for the limitation of this catalog.

A first computer-based execution [11] uses a similar assignment matrix as Ponn for the access. The fields which are empty to this point of time are filled by chains of several effects. Using this computer-based execution, the use of the catalog is simplified and extended significantly. The content of the catalog is based on the works of Roth [12]. However, no additional value is offered in regard to search and reduction possibilities, although a catalog based on a database provides versatile possibilities especially at this point. Than a reduction to the relevant elements can only be executed during the design with different boundary conditions. These boundary conditions can be formed by special points of view, the competence or the preferences of the engineer.

Therefore, the following structure (Figure 2) is suggested for the database-based use of a catalog of physical effects:

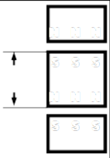
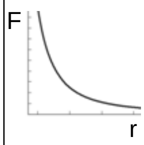
Denomination		**Group of effects/topic area**	**Description**					**Literature**
No.	Name		Sketch	Text	Formula	Graph	Examples of use	
…	…	…	…	…	…	…	…	…
4	Ferromagnetism	Magnetism		A ferromagnetic material consists of spontaneously magnetized Weiss's domains, which can be orientated by an external magnetic field. After removal of external field the orientation maintains.	$F = \frac{1}{4\pi\mu_0}\frac{p_1 \cdot p_2}{r^2}$		Magnetic spring, magnetic clutch	Bronner, 1989; …
…	…	…	…	…	…		…	…

Figure 2. Configuration for basic comprehensive catalog for computer-based use

The combination, reduction and unification of the existing catalogs in order to reach the suggested structure is not going to be explicated here, since this is not the core issue of a catalog of effects for the examination of disturbances. Furthermore, the single elements are not going to be explicated at this point, since they do not differ in their basis from the existing literature and are covered in the literature elaborately. Additionally, their contents are largely comprehensible due to their naming. However, one has to consider the future meaning of the element “literature”. Based on today´s developments, it is likely that a bigger part of the scientific literature is going to be available digitally in near future. This provides the opportunity to store the relevant citations in the element “Literature” for a direct access. This enables the engineer to receive additional information about an effect in a convenient way exceeding the content of the catalog.

During the following examinations of disturbances and robustness, the list or catalogs respectively are reduced in such a way, so that only those elements are contained, which are central at the point of interest or required for the basic understanding. This mirrors the simple use of the reduction possibilities of today´s database systems.

3.2 Extension of the catalog for disturbances

Now, that the basic configuration of the catalog exists, the catalog can be extended in regard to the elements for representing the disturbances.

For this purpose, the catalog is extended with the main element “Disturbances” firstly. Here, the necessary sub-elements within this main element are the “Physical quantity”, the “Disturbance”, the “Description” and the “Literature”. Examining some disturbances it was shown, that an “Illustration” can be helpful. The resulting configuration is shown by Figure 3:

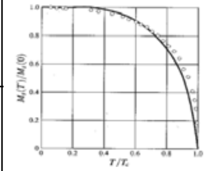
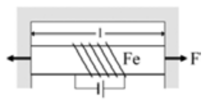
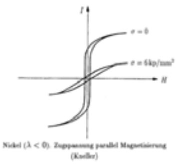
Name of effect	Disturbances				
	Physical quantity	Disturbance	Description	Illustration	Literature
Ferromagnetism	Temperature	Temperature variation	The permeability is influenced by temperature.		Lüders 2010
		Curie temperature	If curie temperature is reached ferromagnetic properties get lost; if temperature is higher than curie temperature the material presents paramagnetic behavior.		Koller, 1997; Meschede, 2006
	Magnetic field	External magnetic field	An external magnetic field is superimposed on the effect of ferromagnetism and influences the direction of the magnetic domains of the material; Cause to magnetostriction the magnet elongates.		Ardenne , 2005; Ehrlenspiel, 2007
	Mechanical load/force	High static load	Ferromagnetism is a property of the crystal, it is dependent on the texture of the magnet and its directions of magnetization; A static load can change the directions, mechanical stress cause a change in the magnetic field; Mechanical load influences the permeability.		Ardenne, 2005; Fasching, 2005
		Impact force	Ferromagnetism is a property of the crystal, it is dependent on the texture of the magnet and its directions of magnetization; An impact force can change the orientation, leading to a demagnetization.		

Figure 3. Extract of catalog of the effect ferromagnetism with disturbances

- **Physical quantity:** The field “Physical quantity” is an umbrella term for the individual disturbances**.** Often, several disturbances arise from one physical quantity. For example, regarding the physical quantity “temperature“ several disturbances arise, such as temperature variation, very high temperature, very low temperature (cryogen temperature) or the Curie temperature.
- **Disturbance:** Within the field “Disturbance” the individual disturbance is listed. The following fields are now attributed to each single disturbance.
- **Description:** Within the field “Description” it is explicated, why and/or how the listed disturbance affects the physical effect. Here, summarized and easily understandable formulations are used.
- **Illustration:** In several cases one can illustrate the impact of the disturbance.
- **Literature:** The field contains information for the particular disturbance regarding the literature where one is able to find the hints to this particular disturbance and its impact. By this, it is possible to receive more detailed information at this point in case the offered description of the catalog is not sufficient for the particular problem. Again, one has to consider future significance of this element when literature can be stored digitally and comprehensively.

After the structure of the catalog element “Disturbances” with its sub-elements has been elaborated now, the information for the filling of this part of the catalog has to be generated for each effect. Here, it turned out that it is advantageously to create a pool firstly containing literature which is interesting and relevant in general. On the one hand, this catalog consists of current scientific literature, such as specialized books, physics textbooks, dissertations regarding physics and technics, or also the existing catalogs. On the other hand, one accesses databases which contain verified information. For example,

these are patent databases such as DEPATISnet and scientific databases such as STN International.
This pool is scanned in regard to the information which is relevant for the examined effect and these results are compiled. Afterwards, the results are looked into collecting hints to disturbances and a list of potential disturbances is elaborated. In the next step, all information which exists about the context between the particular disturbance and the effect is compiled and sorted. Here, the list of the disturbances is updated constantly. During this detailed examination one often detects further disturbances which got lost in the first examination. Using this iterative procedure, an information basis for the affecting disturbances is elaborated systematically.
This information basis is analyzed, structured and summarized thoroughly, so that the single fields of the “Disturbances” can be filled. At the end, this information about every disturbance is to be included in the catalog.
Based on this procedure, 13 effects have been examined up to now and the information has been compiled. Based on the results of these effects, a catalog excerpt was created for the purpose of research and demonstration. Here, those effects have been examined primarily which are necessary for the design of a watch in order to enable further research on the topic of effect structures.
The catalog of physical effects with the contained disturbances is called RD-Effect-Catalog.
The RD-Effect-Catalog allows the engineer to receive hints to disturbances already during the search for effects. This can be used in order to select effects in the aspect of disturbances. Furthermore, he can use the knowledge about the disturbances for a systematic control during the following design and thus it can be used for the design of a robust product. Due to the large number of disturbances, which can exist dealing with many effects, it is difficult to examine the connections between disturbances intuitively within concepts. Often, even the control of all disturbances regarding only one effect seems to be challenging.
Therefore, it is reasonable to create robust concepts not only on the basis of engineer’s competence using the RD-Effect-Catalog. Thus, a simple comparison of the robustness of solutions ought to be possible. The RD-Effect-Catalog provides the basis for the following systematic examinations of robustness dealing with physical effects within the concept design.

4 DETERMINATION OF ROBUSTNESS RATIOS FOR THE SELECTION OF EFFECTS

In this chapter the identification of the three robustness ratios R_I (disturbance based robustness ratio), R_{II} (environment dependent robustness ratio) und R_{III} (sensitivity dependent robustness ratio) is introduced.
The purpose of these robustness ratios is to execute a first estimation of the robustness of effects with little effort and with different states of knowledge. By this it is intended to offer the possibility of comparing and finally of making a selection within the possible effects. The basis of the calculation formulas is formed by the numerically available information from the catalog, the observation of engineers understanding of robustness, as well as information which is to be elaborated for R_{II} and R_{III}.
The only numerical information, which results from the catalog, is whether a disturbance affects the effect or not. The more robust the effect, the higher should the robustness ratio be. Additionally, it will be advantageously, if the robustness has the boundaries one and zero. Within common understanding, something is completely robust, if the robustness is equal one and the robustness is completely non-robust, if the robustness is very little or equals zero as the border case. These thoughts are also basically based on the approaches of the Signal to Noise Ratios (SNR) [13]. However, SNR are based on mathematical functions or series of experiments. Such detailed information is not available during the concept design. Thus, SNR cannot easily be used for the comparing of effects. The proposed formulas orientate themselves by those thoughts; however, they are to be seen as a first suggestion. They possess several disadvantages, which are going to be explicated more.

4.1 Robustness value R_I: disturbance based robustness ratio

For the determination of the first fairly simple robustness ratio one uses only the number of the identified disturbances of the particular effect. This is based on the basic idea, that first of all an effect is the more insensible to an environment, which contains all disturbances, the fewer disturbances generally have an impact on the effect. This matches the situation during the design, when no information about the environment exists. In that case, all disturbances have to be seen as possible disturbances.

Definition: The disturbance based robustness ratio (R_I) is a measure for the number of disturbances which affect the effect in general.

R_I can be calculated by using the formula (1):

$$R_I = \frac{1}{1+\sum D_n} \quad \text{for} \begin{cases} D_n = 1 & \text{if disturbance n affects effect} \\ D_n = 0 & \text{if disturbance n does not affect effect} \end{cases} \tag{1}$$

A corresponding list of disturbances has to be chosen for the summation. In case of the evaluation of R_I, this list matches the disturbances which are listed in the catalog regarding this effect. If one sums up these entries of this list, one simply obtains the number of disturbances, since every $D_n = 1$. Thus, the number of the disturbances could have directly been derived from the catalog. However, in order to enable a consistent formulation and by this an easier understanding of the calculation of all three ratios as well as a better understanding of their contexts, the sum has been chosen for this approach.
The evaluation of R_I of a single effect is done with little effort. R_I can directly be determined, if the literature analysis is complete and the catalog entries are created. R_I can be integrated as a further additional element into the catalog.
Based on a preliminary literature study the R_I shown in Figure 4 for the five possible effects to solve the sub-function give pulse of the example are determinated. In Figure 4 the possible effects are extracted from the complete catalog. The content is reduced to name of effect, sketch, text and R_I. The elements name of effect, sketch and text are important for an easy understanding of the effect. According to R_I the effects can be sorted descending.

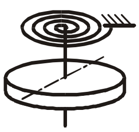
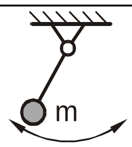
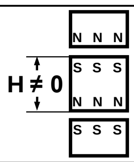
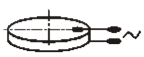
Denomination	**Description**		$\mathbf{R_I}$
Name of effect	**Sketch**	**Text**	
Atomic resonance		Atoms absorb quantum-like amounts of energy in the form of photons to switch to higher-energy orbits and emit photons to switch to lower-energy orbits.	0,5
Hooke's law		A body receives an elastic strain by tension, compression, bending and torsion.	0,25
Gravitation		In the gravitational field of earth bodies are subjected to an acceleration towards the center of earth.	0,2
Ferromagnetic		A ferromagnetic material consists of spontaneously magnetized Weiss's domains, which can be orientated by an external magnetic field. After removal of external field the orientation maintains.	0,17
Piezoelectric		An electrical voltage applies a deformation and vice versa of a piezoelectric crystal.	0,11

Figure 4. Derived list of effects for sub-function give pulse sorted in regard to R_I

A selection of the effects can now be executed on the basis of a minimal robustness R_{Imin} or by the determination of a maximal number of effects, that is to be obtained from the selection. For example, within the watch design a R_{Imin}=0.15 can be determined. By this, according to R_I only the effects

Atomic Resonance, Hooke´s law, Gravitation, and Ferromagnetism are going to be taken into further consideration. The piezoelectric effect would not be included in the further design.
Due to the little information which is used for the calculation, R_I possesses a little informative value. Thus, one has to be careful when using this ratio and it is only suitable for a first, rough selection of the effects. However, this can be very helpful in certain cases. For example, R_I can be used for Quick’n Dirty-Designs, when a single or several robust concepts have to be created with small effort and in an extremely short time. R_I can also be useful if a helpful reduction is needed in the case that many solutions are possible for one sub-function.

4.2 Robustness value R_{II}: environment dependent robustness ratio

For the determination of a more meaningful robustness ratio the environments, in which the product and therefore the effects are going to be used in, are taken into the robustness consideration. Typically, a use takes place in the most different environments. These environments can be characterized by a list of the occurring disturbances as a summary. R_{II} is now based on the idea that only such disturbances can affect the effect which both have an impact on the effect in general and occur within the environment.

Definition: The environment dependent robustness ratio (R_{II}) is a measure for the number of the disturbances which affect the effect within the assumed environment.

R_{II} can be calculated using the following formula (2):

$$R_{II} = \frac{1}{1+\sum D_n \cdot E_n} \quad \text{for} \quad \begin{cases} D_n \rightarrow & \text{from } R_I \\ E_n = 1 & \text{if disturbance n occurs in environment} \\ E_n = 0 & \text{if disturbance n does not occur in environment} \end{cases} \tag{2}$$

The disturbances, which can occur in the environment and might affect the effect, can be identified by using a modeling of the use processes. For this purpose, a systematic analysis of the use processes can be carried out with the help of a process model [14], as it is shown in Figure 5. For the used example, only one use process was examined as a simplification. The assumed use process is the reading of the actual time during a golf game. This process transforms the initial state time unknown into the final state time known. For this purpose one can use a watch. For the designer the watch is the product to be designed. Disturbances influencing the watch occur for example from the process environment, the user and the process. Possible disturbances can be temperature variation, electric field, impact force, high acceleration and magnetic field. These disturbances were identified throughout the process modelling in an intuitive way and should be seen as an example to clarify the principle approach.

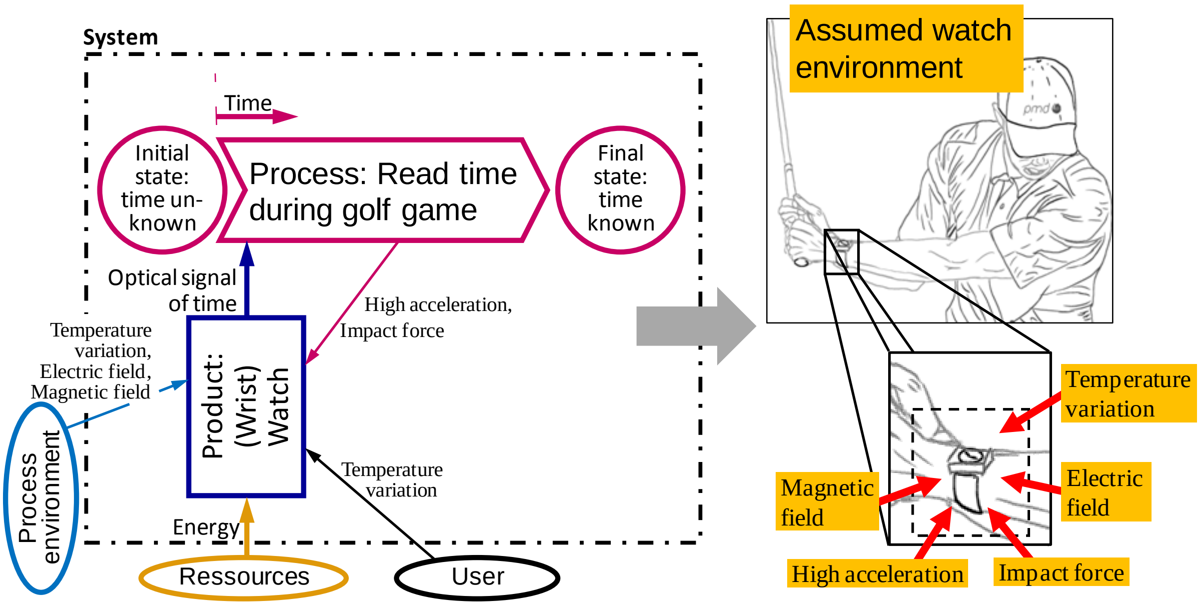


Figure 5. Example of process model and disturbances for read time during golf game

The list of the disturbances which have to be summed up results from the combination of all effect specific lists of disturbances and the list of disturbances of the assumed environment (Figure 6).
R_{II} can be used for a first selection of effects, if it is possible to estimate the environment. By this, R_{II} reflects a more realistic calculation of the robustness than R_I. The selection can be executed using R_{IImin} as well as using a determined minimal number of effects.
However, the required effort for the identification of R_{II} is significantly higher than the effort identifying R_I since use processes have to exist or at least one has to elaborate assumptions about possible use processes. Often, a large number of use processes have to be analyzed and modeled for a largely complete characterization of the environment.

4.3 Robustness value R_{III}: sensitivity dependent robustness ratio

If one assumes, that an effect does not react with the same sensibility to the disturbances, one can consider this for the definition of R_{III}. R_{III} is based on the idea that an effect only has to be examined in regard to its sensibility to those disturbances the effect generally is affected by and which exist in the environment.

Definition: The sensitivity dependent robustness ratio (R_{III}) is a measure for the sensitivity of the effect when reacting to the disturbances in the assumed environment of the intended design.

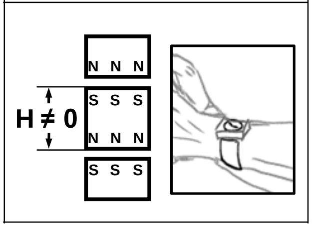
R_{III} can be calculated with the following formula (3):

$$R_{III} = \frac{1}{1+\sum D_n \cdot E_n \cdot S_n} \quad \text{for} \quad \begin{cases} D_n \rightarrow \text{from } R_I \\ E_n \rightarrow \text{from } R_{II} \\ S_n \rightarrow \text{Sensitivity of effect to disturbance n,} \\ \qquad \text{from 0 (insensitive) to 1 (sensitive)} \end{cases} \tag{3}$$

Here, the summation is executed with the same list used at R_{II}, if the considered effects and the assumed environment have not changed. However, the sensitivities of each effect have to be identified for each disturbance existing in the environment (Figure 6).
In this example, the sensitivities were estimated and determined fittingly for the intended design of a watch. This happened intuitively. However, depending to the situation and state of knowledge of the design, different methods can be applied for the determination of the sensitivities [15].
Based on R_I and R_{II}, R_{III} represents a realistic evaluation of the behavior of an effect when affected by a disturbance existing in the assumed environment. Again, a selection can be made based on a R_{IIImin} or a determined minimal number of effects. However, the effort to evaluate R_{III} increases significantly compared to R_{II}. The effort is basically dependent on the methods which are used for the evaluation of the sensitivities.

n	Disturbance	D_n	E_n	$D_n \cdot E_n$	S_n
1	Temperature variation	1	1	1	0,9
2	Cryogen temperature	0	0	0	0
3	Curie temperature	1	0	0	0
4	Load cycle	0	0	0	0
5	Impact force	1	1	1	0,6
6	High static load	1	0	0	0
7	High acceleration	0	1	0	0
8	Electric field	0	1	0	0
9	Magnetic field	1	1	1	0,8
10	Strong gas circulation	0	0	0	0
			Summation:	3	2,3

Ferromagnetism in wrist watch while playing golf



$$R_{II,Ferromag.} = \frac{1}{4} = 0{,}25 \qquad R_{III,Ferromag.} = \frac{1}{3{,}3} = 0{,}3$$

Figure 6. Determination of R_{II} and R_{III} for ferromagnetism in wrist watch while playing golf

4.4 Critical reflection on the robustness ratios R_I, R_{II}, and R_{III}

The presented robustness ratios enable the calculation of robustness in an easy way only on basis of disturbances which can affect the physical effects. However, due to the current model of calculation a strong nonlinearity exists. According to this, the robustness changes more significantly, if a second disturbance is added to only one disturbance, than it changes, if one disturbance is added to five disturbances. Of course, this does not match the real changes of robustness and may lead to misinterpretations by the engineer. In addition, the derivatives of inversely proportional functions are difficult to calculate. This may cause problems in future examinations, when further information is to be gained from the derivatives. In future, these stated problems are going to be solved by revising the formulas in cooperation with mathematicians.
Basically, the evaluation of R_I, R_{II}, and R_{III} on the basis of the RD-Effect-Catalog has to be seen critical in regard to literature and research. On the one hand, the literature analysis has to exist completely for all effects in order to enable a comparison. On the other hand, the number of the identified disturbances is dependent on the used literature and its contained state of scientific knowledge. If only one disturbance is found for an effect or if it has not been identified during the literature analysis first, the ranking of the selected effects will change. Also a changing of the selection is possible. This applies for all three robustness ratios and always has to be considered during their use.

4.5 Evaluation and selection of the effects based on the robustness ratios

Examining the three robustness ratios together for the example (Figure 7), one notices that the effect atomic resonance achieves the best results regarding all three ratios. This effect is only slightly affected by temperature. This matches the fact that atomic clocks are widely-used today and have asserted themselves as the essential pulse generator. However, at this point this cannot be traced back to its high robustness directly, since there are surely a large number of most different factors which lead to this evolution.

Effect	Robustness ratios		
	R_I	R_{II}	R_{III}
Gravitation	0,2	0,25	0,37
Hooke's law	0,25	0,33	0,59
Piezoelectric	0,11	0,20	0,41
Atomic resonance	0,5	0,5	0,91
Ferromagnetic	0,17	0,25	0,30

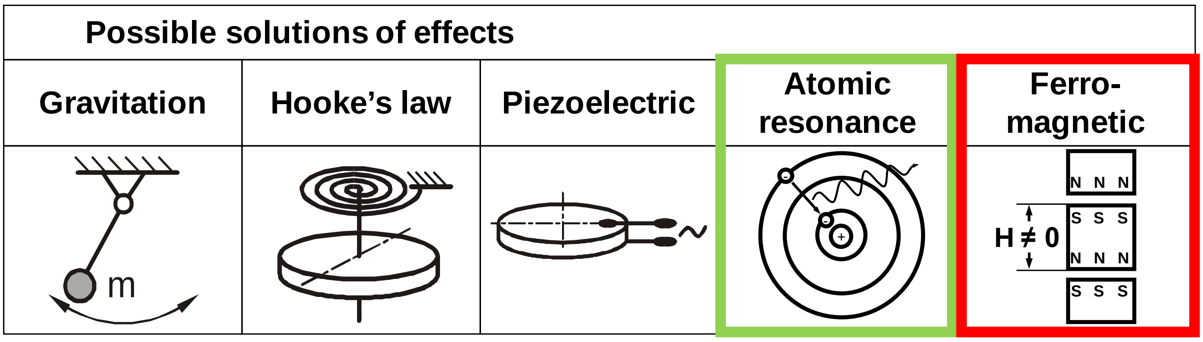


Figure 7. Examination of the robustness ratios R_I, R_{II}, and R_{III} of all solution possibilities for the sub-function give pulse of the example

Altogether, it can be noticed that the effect ferromagnetism is the least robust effect. An interesting example is the current concept design Pendulum of the company TagHeuer. TagHeuer uses the ferromagnetic effect for give pulse in form of a virtual spring. "One problem stays unsolved (up to now): the temperature sensitivity of the magnet" [2]. This general sensitivity to temperature can be identified with the RD-Effect-Catalog. If this had been known during the early phases, this unfavorable design might have been avoided. If one decides to hold on to the concept, additional measures will have to be defined in the next design phases, since many uncertainties can still be controlled by according measures in the embodiment and final design [16].

5 CONCLUSION

Within the presented approaches an RD-Effect-Catalog has been developed and the calculation of robustness ratios concerning physical effects has been elaborated.
Here, one was adverted to the generation of a basic comprehensive effect catalog. A realization based on a database is required for the use of the catalog due to the extent and especially to the versatile access and use aspects. This basic catalog has been developed further by the integration of disturbances and their describing elements and by this a RD-Effect-Catalog has been obtained.
On the basis of the known disturbances in regard to the individual physical effects it is possible to define robustness ratios of the effects. Here, R_I (disturbance based robustness ratio) focuses only on the known disturbances, R_{II} (environment dependent robustness ratio) additionally takes an assumed environment into consideration and R_{III} (sensitivity dependent robustness ratio) examines the sensitivity of the effects in regard to each single disturbance of the environment.
By generating these robustness ratios it is possible to evaluate and to compare different solution possibilities of a sub-function in regard to their robustness. The different ratios differ from each other due to their different expressiveness and the effort required for their calculation. One has to consider that the robustness ratios on the basis of the RD-Effect-Catalog have to be seen critical in regard to literature and research.
Robustness can be used due to these robustness ratios as a criterion for the selection of the effects. By this, a basis for the methodically supported development of robust concepts exists. The examinations of disturbances and the calculation of the robustness ratios are going to be extended to the aspects of effect chains and effect networks. For example, effect chains are created by the generation of combinations arising from the morphological system, by which conceptual solutions can be developed systematically. This can be used as a support for the systematic RD-process in order to design robust concepts from the beginning of the design.
In future, it is going to be examined whether the concept can be transferred to further kinds of catalogs, such as design catalogs.

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