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Proposition of an approach applicable during the design process of working equipment to identify potential hazards for workers

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Abstract

The work of product designers has to evolve in phase with the improvements made to technology and changes in regulations. They have to work on different aspects of a product such as its technological, legal, environmental and occupational safety implications. European directive 2006/42/CE promulgates safe machine design principles to prevent professional risks. These principles guide machine designers to reduce residual risks as much as the technological state of the art permits. Special machine designers are by definition confronted by a lack of specific standards relating to *a priori* risk analysis. The aim of this paper is to present an original approach to help them to identify hazards upstream and also throughout the design process.
This approach is based on the fact that hazards are linked to the presence of energies. Hazard identification can be done through the detection of parameters linked to energy sources and flows. The approach then feeds back information to designers about potential contacts between energies and workers, to highlight the need to add preventive measures.
We use the Functional-Structural Model is used to represent the machine energy architecture through the different steps of its lifecycle. Thus it is possible to identify every interface through which energies circulate. These interfaces are defined by two kinds of parameter: energetic parameters (linked to energy properties), and other design parameters.
This paper first presents a detailed classification of energetic parameters that are also indicators of the hazards present in the machine. We then present logical rules for processing these energetic parameters and others, in order to increase the accuracy of the hazard identification performed. To conclude, the results obtained from using this approach during the industrial design of a supply line is detailed to validate the pertinence of its application from the earliest design stages, with improved accuracy during the subsequent design stages.

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Keywords: design; machine; working equipment; methodology; energy; hazard identification; risk; safety; worker; operator.

1. Introduction

The work of machine designers has evolved in line with the evolution of technologies, laws and society. They can no longer limit their work to the design of a solution that will only resolve a technological problem. Besides the latter, they have to simultaneously consider problems linked to financial, time-based, environmental and safety aspects [1, 2].

In 2014, out of the 621 111 work accidents declared in France, about 8% were associated with machines, and thus partially with production equipment, according to French statistics on professional accidents. Regarding these accidents in particular, and more generally occupational health and safety, design is a path of prevention whose advantages no longer need demonstrating and is known as "integrated prevention". This approach is codified by European directive 2006/42/EC, known as the "Machinery" directive, and by its associated standards. The prevention strategy recommended in these texts focuses on *a priori* risk assessment. It gives the machine designer the objective of obtaining the lowest possible risk level according to the state of the art.

However, except for some catalogue machinery for which specific standards exist (known as type "C") and which are subject to this risk assessment, special equipment designers

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must rely on transversal standards (types “A” and “B”), and especially standard NF EN ISO 12100 related to general design principles.

It is important to underline that in France, production equipment is mostly designed and manufactured by small and medium enterprises (according to the 2014 data of French Chambers of Commerce and Industry). Therefore, since designers belonging to these SMEs are not specialized in prevention and have no formal resources or tools adapted to perform *a priori* risk assessments, they are limited on the one hand to the risk families closest to their field of experience (e.g., mechanical) and, on the other hand, to carrying out this assessment at the end of the project, once all the technical solutions have been selected. Furthermore, the information required for risk assessments (severity of harm, frequency, exposure, probability of occurrence, possibility of avoidance) are not just linked to design data, thereby widening the gap between design and safety. Occupational health and safety requirements are thus treated as constraints of adaptation and correction instead of design.

To solve this issue, we propose a method to assist special machine designers to systematically identify hazards, an essential step of risk assessment. To be more efficient, this approach must verify the four following characteristics:

- generic: faced with the different hazard types, the design process implemented and the type of machine;
- inductive: based on the design parameters (causes) to identify hazards (effects) through parameters used in risk assessment methods (e.g., NF EN 1005 for ergonomic hazards or directive 2001/59/EC for chemical hazards);
- dynamic and traceable: monitoring the evolution of system characteristics and the configuration of components from the outset and during the different design stages;
- integration and/or compatibility with current design elements: ensuring interoperability and ease of use through monitoring and indicators in order to quantify and use data.

2. Literature review

For the sake of this paper clarity, we define and organize the main terms linked to design based on the literature. Thus we consider that a design approach is a set of design phases (e.g., architectural design) that structure design activities (e.g., drawing creation). The latter are composed of five design tasks, sources of design data (e.g., parameters, intermediate objects). The intermediate objects (IO) punctuate and link the design activities and guarantee the design parameters maturity [3-5].

2.1. Design approaches

Different works on design have been identified in the literature to cover a lot of problem the designer can meet: design process management, decision-making, environmental or safety problems [2]. These works can be approaches, methods or tools and can cover all or a part of the design process [6-9]. Consequently, a wide range of elements structure the designer’s work. However, according to [5], design activities can be divided into five generic tasks: creation, dimensioning, representation, optimization /evaluation and validation.

To maintain the generic objective toward the design process followed by designers, the method will therefore use these elementary tasks, intermediate objects [3] and the parameters generated from them, since they are independent from design approaches and activities. This point is essential as the enterprises targeted are mostly VSE/SMEs which do not follow well a formal design approach.

2.2. Risk prevention in design

Numerous articles on risk reduction in the design process were found in the literature [10, 11]. We focused this literature review on hazard identification since it belongs to the risk analysis process.

Research works on integrating risk analysis in production system design mainly focuses on two paths: the design process organization and risk evaluation, but in both cases these works present limits regarding the problematic of this paper.

Works that focus on the design process mostly propose methods that call on collaborative project reviews [12, 13]. The reduction of risk in general, and the identification of hazards in particular, are based on cooperation between the different actors during these project reviews. Therefore this type of approach does not guide the designer in decision-making when they work independently in front of their workstation [14]. Furthermore, when these project reviews are performed using numerical mock-ups or physical prototypes, this type of approach must be sufficiently advanced in the design process to analyze the risks [15].

Regarding studies on risk assessment and evaluation [11, 16], i.e. the determination of an index used to classify potential risks, they are generally specific to a single type (e.g., mechanical risk [17]). Moreover, these methods are focused on the combination of the different parameters involved in assessing risks. These parameters are similar from one method to another. As recommended by standard NF EN ISO 12100, these parameters include severity of harm, frequency/ duration of exposure, probability of occurrence of a hazardous event and the possibility of avoidance. The main differences between the proposed methods concern the number of levels used to evaluate these parameters and how they are combined (e.g., matrix, graph, numerical equation, abacus, chart). Consequently, these works do not provide an answer to the previously highlighted problem, which aims to identify hazards.

Analysis of the literature nonetheless made it possible to identify four approaches that *a priori* provide an answer to this paper problem and satisfy the expected criteria (generic, inductive, dynamic and integrated):

- Coulibaly *et al.* [18] proposed a Risk Factor (FRis) indicating whether a risk is present or not. This paper has the same goal but FRis indicator requires parameters that are not naturally created during the design process;
- The “PAG” multi-agent system [19] is a system to analyse the performance of working situations based on numerical mannequins. Its integration in the designer’s tools is ideal,