Safety and Reliability Aspects

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The application of active magnetic bearings for rotating machinery has become state of the art and ranges from research prototypes to industrial applications, from small turbo-molecular pumps to powerful pipeline compressors in the megawatt range. Users are aware that, beyond function, the safety and reliability of this equipment is critical to its continued commercial development. Safety is more than a mere technical issue. It contains a strong component of psychological interpretation, and societal demands for safety in machinery are ever increasing. Reliability, on the other side, has a definitely technical touch, and it appears to be more amenable to engineering calculations and to economic considerations. Mathematical tools for assessing reliability of classical technical systems, and performance numbers for comparing them, such as mean time between failures, are readily available. The reliability analysis of given technical structures and systems, consisting of a more or less large number of classical components, is rather well developed [33]. However, the active magnetic bearing is not a classical technical system. It is a typical mechatronic product, and as such it contains information processing components, software and feedback loops. For such components, in particular for software, reliability analysis is still under development. In addition, the synthesis of a safe mechatronic system, the method of designing it, is not structured in a systematic way. There is a strong opportunity, however, to make mechatronic systems, despite their obvious complexity, more reliable than classical ones. It is the potential of internal information processing, somehow resembling the ability of living beings to use information to increase their chances of ‘survival’, which could make mechatronic systems more reliable.

This chapter will, firstly, address conceptual questions of safety and reliability, in particular, stating that it is theoretically not possible to build a fully safe system. Philosophical reasoning on the logic of science shows that safety can only be improved, step by step: it cannot be guaranteed. Subsequently, the main emphasis is put on the technical side of safety and reliability for AMB/rotor systems. Section 18.3 will give a survey on failure examples in mechatronic systems and AMBs. In Sect. 18.4, means for reducing the
risks of failure will be discussed. First, safety and reliability are put into the framework of quality management and design, and then more specific ways of dealing with AMB are considered. Redundancy schemes, exception handling and robust control are proven tools, and examples are given. The fail/safe operation with AMB systems requires additional touch-down bearings. The state of the art in modeling the nonlinear rotor dynamics in contacting the touch-down bearings, drop tests, and design for specific applications are referenced. Guidelines for the design of touch-down bearings are summarized. The design of touch-down bearings still needs further research.

The potential of AMB/rotor systems to become fault-tolerant is seen as a general feature of smart machinery. “Smart” means that such a machine knows its state — as it already has sensors and internal control loops for its functionality — and makes best use of the internal information processing capabilities within the machine to optimize its state. Examples of the design of fault-tolerant AMB, using diagnostics, identification methods and reconfigurable control will be discussed and referenced. It is expected that future research will support these trends and make them available for further applications, contributing to the already very impressive, but still growing, safety and reliability features of AMB’s.

### 18.1 Psychological and Philosophical Background of Safety

Safety is an ambiguous term, and it is important to see the non-technical side of it as well. Danger has always been an immanent part of human life, and safety, the absence of danger, is precious. Dangers may come from environmental catastrophes, wild animals, unknown enemies, or unexpected illness. It is a permanent effort of our society to convert danger into risk, to make it calculable and controllable, to tame fate. Dams have been built to avoid flooding, wild animals have vanished to the zoo, and against illness and death we have, at least, insurance to mitigate the consequences. Technical means to increase safety in advanced products, nowadays, are mainly based on mechatronic methods. Driving a car has been made safer by mechatronic driver assist systems, which control dangerous situations, such as braking or skidding.

The acceptance level of danger and risk has a strong psychological background and varies with emotional attitude, habits, and individual exposure. Let some examples speak for themselves, without dwelling on arguments or further explanations: car accidents versus train accidents, smoking and drinking habits even against medical advice, danger in hobby sports versus danger in work conditions. In hobby sports, people even enjoy the thrills of risks, be it bungee jumping, or car racing. A nice headline-making example is shown in Fig. 18.1, which could initiate lively discussions on various safety aspects.

On the philosophical side, safety might spur some discussion as well. The philosopher Karl Popper [34], in his famous treatise “Logic of Science”, 1934,