"Safety in Human-Robot Collaboration"

1 Introduction

Possible collaboration of humans and robots in shared workplaces without perimeter guarding opens up new possibilities and concepts in industry and production. The standardisation and legal situation allows for human-robot collaboration (HRC) within defined limits.

This document provides guidance for manufacturers, distributors and integrators and points out relevant rules and standards. This document and the standards mentioned herein serve to provide information for end customers (operators).

To implement such workplaces it is necessary to study the Machinery Directive (law) and standards thoroughly. A risk assessment must be done for each individual application. This position paper has been developed by member companies of the VDMA Robotics group in cooperation with the Scientific Society for Assembly, Handling and Industrial Robotics (MHI e.V.).

2 Basics of Human-Robot Collaboration (HRC)

In robotics, the term "collaboration" (lat. con- = "with-", laborare = "work") refers to cooperation between humans and robots. This cooperation is limited to a precisely defined collaborative workspace.

The four basic safety principles applicable to HRC are:

1. **Safety-rated monitored stop**
   Robot stops when operator enters the collaborative workspace and continues when the operator has left the collaborative workspace.
2. **Hand guiding**
   Robot movements are controlled actively by the operator through suitable means.
3. **Speed and separation monitoring**
   Contact between operator and moving robot is prevented by the robot.
4. **Power and force limiting**
   Contact forces between operator and robot are technically limited to a safe level.

These four basic principles of protection in HRC are described in detail in the standard EN ISO 10218 "Robots and robotic devices - Safety requirements for industrial robots", Parts 1 **[1]** and 2 **[2]** as well as in ISO/TS 15066 "Robots and robotic devices – Collaborative Robots" **[3].**

Legal note

The position paper serves as a guideline and provides an overview of relevant standards, laws and requirements regarding the safety in the collaboration between humans and industrial robots to the manufacturers of robot systems.

It does not claim completeness or provide an exact interpretation of the existing statutory provisions. Other constellations are conceivable.

Neither does it replace the study of relevant guidelines, laws and regulations. In addition, the speciifics of the respective products and their different fields of application have to be considered.

In all cases involving HRC, protection of the human must be ensured by safety measures. The technology used must meet certain safety requirements. According to the risk assessment the essential safety and health requirements are determined and corresponding measures are taken.

3 Machinery Directive

The Machinery Directive (2006/42/EC) **[4]** issued by the European Parliament provides for a uniform level of safety and health protection for machinery that is brought into circulation within the European Economic Area (EEA). Each EU member must transpose the Machinery Directive into national law. In Germany, this is done by the "Produktsicherheitsgesetz" ("product safety law").

By the EC-Declaration of Conformity, manufacturers or EU importers (normally the system integrator) declare that the product meets the requirements as defined in Community harmonisation legislation. Then, a CE mark is issued.

One of the most important prerequisites for CE marking of a (complete) machine, i.e. of the robot application as a whole, is a risk assessment and the implementation of the resulting safety measures. These steps are described in EN ISO 10218-2 **[2]**. Underlying fundamentals are detailed in EN ISO 12100 "Safety of machinery – General principles for design – Risk assessment and risk reduction"**[5]**. If risk-reduction is done by control system, the requirements described in EN ISO 10218-2 **[2]** and EN ISO 13849-1 "Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design" **[6]** must be met. In the sense of the Machinery Directive, industrial robots are so-called "partly completed machinery" and are not CE marked; they must be supplied with a so-called "Declaration of Incorporation". The installed application with robot, tooling and fixtures, however, shall meet all requirements of the Machinery Directive and then is CE marked.

4 Risk Assessment

The first step is always to specify precisely the application including all boundary conditions and components. Risk assessment must then define the necessary technical safety requirements. It determines whether a risk reduction is required and whether hazards must be eliminated or reduced by protective measures. An example for such a measure in the context of a robot system would be safe reduced speed in combination with safe collision detection. Only when the final risk assessment confirms that an acceptable safety level has been reached can a CE mark be issued.

Risk assessment must take into account the various aspects of HRC. This must include so-called "intended use" as well as "foreseeable misuse" by persons within reach of collaborative robots.

The procedure of assessing the application as well as the description of safety related requirements are described in detail in the standard EN ISO 10218 parts 1 and 2 **[1][2]**.

The following concentrates on power and force limiting.

Since in this method of collaboration contact between human and robot may occur, conventional safeguarding measures (e.g. fixed guarding) are replaced by protection against impact (limiting speed for transient contact) and protection against crushing (limiting force for quasi-static contact). Apart from suitable mechanical design, limiting speed and force by control are possible measures to reduce risk in such applications. Means to fulfill the biomechanical limits of ISO/TS 15066 **[3]** must be implemented in a safety-rated manner. A practical guideline for implementing the requirements can be found in the DGUV Information "Collaborative robot systems" **[7]**.

In such applications contact between human and robot is usually provoked by the human interfering with the path of the robot. Appropriate ergonomic design therefore should allow for the human to avoid such contacts.

Conclusion

- Human-robot collaboration cannot be deployed without risk assessment.
- The overall application must always be considered (process, fixtures, gripper system, robot), i.e. not only the robot.
- Safety functions must be implemented using suitable components in accordance to determined requirements.

5 How do standards help?

In order to meet the Machinery Directive, manufacturers, distributors, integrators and end users can apply the relevant harmonised European standards.

Observing the standards leads to the so-called "presumption of conformity" which means, if the standard is fulfilled, compliance with the Machinery Directive can be "presumed" and does not need to be verified individually. Not using the normative technical safety requirements results in the obligation to provide evidence that the complete system achieves an equivalent or higher safety level.

Standards must be applied in their current versions. Thus, for example, a maximum power of 80 W or a contact force of 150 N as stated in EN ISO 10218-1:2006 are no longer valid.

As harmonised European standards are frequently based on the international standards of ISO or IEC or are direct adaptations of these, the advantage of compliance to these standards when constructing robots or designing applications is that conforming solutions can also be offered beyond European borders.

6 Technical Safety Requirements

To avoid hazards to persons also in the event of a fault in the system, control-related measures for maintaining limit values must be implemented in a safety-rated manner. The term "safety-rated" is described in EN ISO 13849-1 **[6]** by means of categories and performance levels and must be applied to all safety-relevant components.

In the robot safety standard EN ISO 10218-1 **[1]**, the safety functions of the robot controller are determined to be implemented in category "3" with performance level "d" unless risk assessment indicates a higher or lower level.

Category 3 means a cross monitoring, dual-channel system. It is not sufficient, however, e.g. to use two identical components. The safety performance level (PL) determines the required residual probability of dangerous failure.

Risk assessment of a specific complete application results in the required performance level. The system integrator is responsible that all applied safety functions (e.g. monitoring of the robot speed and contact force) meet this required performance level before the application is put into operation. When selecting the robot and other components, it must be confirmed that the required safety functions are provided with the required performance level.

It should be noted explicitly that the manufacturer of a particular system or application is responsible for compliance to safety requirements (self-certification). He can seek consultation or support by external experts. Robot manufacturers, by analogy, can self-certify the safety functions of their robots.

7 References

[1] EN ISO 10218-1:2011 "Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots" (ISO 10218-1:2011).
[2] EN ISO 10218-2:2011 "Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration" (ISO 10218-2:2011).
[3] ISO/TS 15066:2016 "Robots and robotic devices – Collaborative robots". .
[4] Machinery Directive 2006/42/EC.
[5] EN ISO 12100:2010 "Safety of machinery - General principles for design - Risk assessment and risk reduction"(ISO 12100:2010).
[6] EN ISO 13849-1:2008 "Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design" (ISO 13849-1:2006).
[7] DGUV Information "Collaborative robot systems" (www.bghm.de).

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