Machine safety with collaborative press brake application

Pirttilahti J[1]., Hirvonen J[1].

1 Seinäjoki University of Applied Sciences

KEYWORDS: cobot, press brake, metal manufacturing industry

ABSTRACT

In this paper, we present a collaborative press brake application that uses a collaborative robot (also known as a cobot) to perform a series of operations on a series of sheet metal parts. The benefits of the automated machine operation mirror those of automating production tasks in general: improving efficiency and accuracy and freeing up workers to perform other tasks while the series is in production. This application is equipped with a safety scanner and ABB's SafeMove function to meet the stringent machine safety standards. The paper discusses the harmonized machine safety standards and risk assessment required to evaluate the application and presents the process and the results of the risk assessment of this application. The ISO 12100 standard is used as a reference framework for risk assessment and mitigation. The article also compares a real application using a collaborative robot with a simulated application using an industrial robot in the same machine tending task. The aim is to compare the safety characteristics required for a collaborative robot application and a traditional industrial robot application.

The results of the article show the differences between a real collaborative robot application and a simulated industrial robot application. The main conclusions are that the use of a collaborative robot makes material flow management more flexible and application programming and minor modifications easier. In addition, the use of a collaborative robot saves expensive floor space in production. SMEs have also shown interest in integrating a robot into an older production machine already in use as a cost-effective way to modernize and improve productivity. In practice, however, a collaborative robot cannot usually run a series as fast as an industrial robot because it is not isolated by fences, and the high speeds of an unisolated robot are usually dangerous from a machine safety point of view. In addition, an industrial robot has a better load-bearing capacity than a collaborative robot. Nevertheless, the application attracted the interest of SMEs because of its production efficiency and staff involvement. In addition, the mobile collaborative robot station used in the application attracted the attention of the SMEs because of its versatility. However, current standards require the station to be stationary during the risk assessment process and the risk assessment of a collaborative robot is generally a more demanding process than for a traditional fenced industrial robot. Yet, the benefits of flexible and collaborative manufacturing processes make it important to investigate risk assessment examples to facilitate broader adoption of such applications.

INTRODUCTION

As generations age, finding skilled labor for the metalworking industry is becoming increasingly difficult [1, 2]. The problem is compounded by the fact that younger generations are less interested in the physical work of the industry and in learning the traditional skills required of production workers. In addition, the increasing complexity of products and quality requirements, as well as the general shortening of working lives and increased competition, particularly in SMEs, pose significant challenges for the training and qualification of staff. This is a big problem in Finland, as the metal industry's share of the sold production was 40% in the year 2022 [3].

Robotics has been present in the metalworking industry for decades and its role has increased with technological progress and decrease in price [4]. According to the International Federation of Robotics (IFR), the number of global robot installations has risen from 159 000 units to 553 000 units between 2012 and 2022. In Finland, the corresponding rise was from 330 units to 631 units – however, the peak year was 2016 with 699 installations [5]. The forecast of the annual global market growth from 2023 to 2026 is 7% [5]. Globally, the three biggest sectors using industrial robots are the electronics industry (28%), the automotive industry (26 %) and the mechanical engineering industry (12%) [5]. In Finland, the mechanical engineering industry was responsible of over 42% of the new robot investments in 2022 [5]. Robotic applications in the metal sector have mainly focused on welding and related processes and machine service [4].

In recent years, the integration of collaborative robotics, known for its versatility and safety, has increased in many applications and uses as technology has developed. There is no separate statistics for collaborative robotics, but in general it is known that the global market share has already increased to 10% of the total of investments, which for Finland would correspond to the trade of approximately 60 units annually [6]. The most typical industrial applications of cobots are assembly, pick and place tasks, and material handling [7]. Also, welding tasks have recently become more common especially within SMEs [7, 8]. Applications have also seen an increase in the integration of collaborative robotics to work with older production machines.

Safety in industrial cobotics is an important aspect, and research has been conducted in different areas including collision prevention, prediction of human intentions, and risk analysis approaches [9]. A safety design process for collaborative robots has also been defined [10]. The process includes applying the relevant safety standards, performing a risk assessment for the application and the chosen tools, and assessing the adequacy of the internal safety functions [10]. In general, one of the main challenges in applying the standards is to identify the relevant risks for the company and to implement appropriate measures to reduce the application-specific risks to a tolerable level. The harmonised standards provide comprehensive, general guidelines, but applying the standards to achieve the required level of safety places a considerable amount of responsibility on the user. For this reason, in addition to carrying out high quality risk assessments, examples of risk assessments are crucial in providing guidance for comprehensive risk management.

This paper presents a collaborative press brake application using a cobot, which is then compared with a simulated industrial robot application to achieve the same manufacturing purpose. The risks of the application are determined by the relevant standards. This article states that conducting a risk assessment for a collaborative robot, despite the novelty of the products, is implementable. Furthermore, in such applications, it is possible to achieve a higher level of safety more cost-effectively with a collaborative robot than with a standard industrial robot. The paper is organised as follows: first, the risk assessment for the real and simulated application is carried out, then the main results of the risk assessment are presented, then the conclusions are presented, and the last sections include acknowledgements and references. We also emphasise that the ultimate responsibility and integrity of the risk assessment lies with the user.

RISK ASSESMENT

In order to provide a risk assessment for the application introduced earlier, the relevant harmonized standards must be taken into account for the general risk assessment structure, and for finding the application specific risks for the collaborative press brake solution and for the simulated industrial robot solution. The general risk assessment and reduction strategy of ISO 12100-1 introduces a five-step procedure [11]. First, the limits and the foreseeable misuses of the machine are identified. Second, the hazards and associated hazardous situations are identified. Third, the risk is estimated for each identified hazard and hazardous situation. Fourth, the risk is evaluated and decisions are made to reduce the risk. Finally, in the fifth step, the hazard is eliminated or the risk associated with the hazard is reduced by protective measures [11].

***Figure 1**: Servo press brake machine integrated with a collaborative robot.*

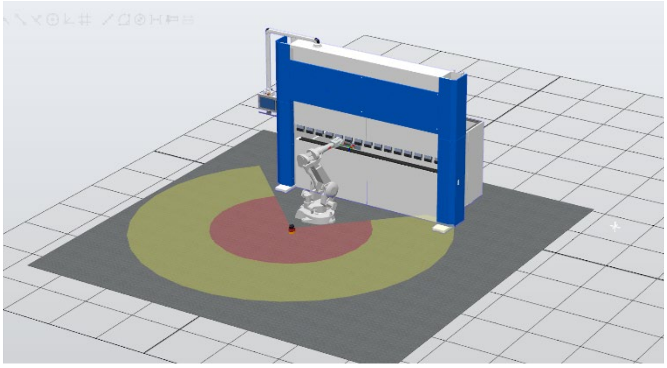

Figure 2*: Simulated example environment (notice: safe zones only for example)*

The first step is to determine the limits of the machine. Figure 1 shows the real application where CoastOne Cone G25 servo press brake and ABB Gofa CRB 15000 are integrated together to achieve an automatic bending cycle. The press brake could be used separately when the robot is not in automatic mode. In the simplified simulated application, the collaborative robot is replaced by an ABB IRB 2400 industrial robot. That is shown in Figure 2.

The applications have several things in common. The intended use is the automated bending of sheet metal parts, with material handling performed by either a collaborative industrial robot or an operator and actual forming performed by a servo-operated press brake.

Operating modes include automated cycles and, for the collaborative solution, manual cycles when the robot is not in operation. Operators must be suitably trained and agree to use the machine in a safe manner. All workspaces must accommodate the robot's range of motion and the press brake's operations. Safety zones with detection devices are required to prevent unauthorized access during operation and to slow down or stop the machines if approached.

The foreseeable misuses in a collaborative press brake solution include improper loading, unauthorized operation and misuse of the space required for safety scanners as storage. Robot movement requires adequate space, and operators need basic training in robotic systems and press brake operations. The collaborative nature allows both automated and manual modes.

A simulated industrial robot solution has the same assessment as a foreseeable misuse as the collaborative application, but because this application uses an industrial robot without physical barriers, it requires larger safety zones due to higher speeds and forces. Operators and factory personnel need special training to work near the robot. The risk of hazards is greater when the press brake is operated manually.

In the second step of identifying application-specific hazards, the following standards were used: ISO 10218-2: Robots and robotic devices – Safety requirements for industrial robots – Part 2: Robot systems and integration [12]; ISO TS 15066: Robots and robotic devices – Collaborative robots [13]; ISO 11161: Safety of machinery – Integrated manufacturing systems – Basic requirements[14]; and ISO 12622:2009 +A1:2013: Safety of machine tools – Hydraulic press brakes[15]. In addition, the draft ISO 6909: Machine tools – Safety – Presses provides useful information for identifying and analyzing hazards and risks for the application in question, as it includes servo-operated press brake systems [16].

For this article, the risks presented are limited to the mechanical hazards. Once the hazards have been identified, the third step is to assess the hazards. Table 1 provides the hazard and risk analysis and the mitigation measures for the collaborative robot solution and Table 2 for the simulated industrial robot application. The tables also include the reference to the standard where the hazard is mentioned. The high-risk mechanical hazards are listed in the first columns of the tables. The risk for each of the hazard is estimated according to ISO 12100 [11] by analyzing the severity and the probability in columns. In the fourth step, the risks are evaluated and the decisions on the need for risk reduction are presented in fourth column. The decisions presented in the table also include the fifth step, where the hazard must be eliminated, or the risk associated with the hazard must be reduced by means of protective measures. The mitigation measures are presented in the fifth column. Tables 1 and 2 are provided only as an example and their use is the responsibility of the personnel responsible for its application.

***Table 1**: Hazard identification, risk evaluation and risk mitigation for the collaborative robot solution.*

Hazard	Severity (Collaborative Robot)	Probability (Collaborative Robot)	Risk Evaluation (Collaborative Robot)	Mitigation Measures (Collaborative Robot)	Standard Reference
Pinching points	High (severe injuries or amputations possible)	Medium (occurs if safety protocols are not followed)	Not acceptable; requires immediate mitigation.	Install physical guards around the pinch points, use safety sensors to detect operator presence and stop machine movement, implement emergency stop buttons within easy reach of operators and provide comprehensive training on safe operating procedures.	ISO 10218-2 [12]
Collisions with robot arm	Medium (bruises, fractures, or equipment damage)	High (frequent interaction with moving robot arm)	Not acceptable; requires immediate mitigation.	Implement safety sensors and ABB SafeMove to monitor and control the robot's movements, define and enforce safety zones around the robot's operating area, use collision detection systems to prevent accidental contact and employ slower speeds or increased awareness modes when operators are nearby.	ISO/TS 15066 [13]
Cutting hazard	High (severe cuts, lacerations, or amputations possible)	Medium (depends on handling and exposure to sharp edges)	Not acceptable; requires immediate mitigation.	Install guards and protective covers over sharp edges and cutting areas, use safety sensors to detect operator presence and stop machine movement near cutting zones, provide PPE such as cut-resistant gloves and sleeves, conduct regular safety training to emphasize the dangers of sharp objects and proper handling techniques and implement safe work procedures, including the use of tools or fixtures to handle sharp objects instead of direct manual handling.	EN 12622 [15]
Crushing and shearing hazards	Medium (collaborative robot has force and torque sensors the servo press brake could be misoperated)	Low (rare but critical)	Not acceptable; requires mitigation.	Install physical guards around the pinch points, use safety sensors to detect operator presence and stop machine movement, implement emergency stop buttons within easy reach of operators and provide comprehensive training on safe operating procedures.	EN 12622 [15]
Entanglement hazards	Medium (minor to severe injuries possible)	Medium (depends on presence of loose clothing or hair)	Not acceptable; requires mitigation.	Install guards and covers over moving parts to prevent entanglement, provide PPE such as hairnets and tight-fitting clothing and conduct regular safety training to highlight the dangers of entanglement.	EN 12622 [15]
Unexpected movement of machines	High (severe injuries or fatalities)	Medium (can occur due to control errors)	Not acceptable; requires immediate mitigation.	Install emergency stop functions and fail-safes to prevent unexpected movements, use ABB SafeMove to monitor and control machine movements and conduct regular checks and maintenance of control systems to ensure reliability.	ISO 10218-2 [12]

***Table 2:** Hazard identification, risk evaluation and risk mitigation for the industrial robot solution.*

Hazard	Severity (Industrial Robot)	Probability (Industrial Robot)	Risk Evaluation (Industrial Robot)	Mitigation Measures (Industrial Robot)	Standard Reference
Pinching points	High (severe injuries or amputations possible)	Medium (occurs if safety protocols are not followed)	Not acceptable; requires immediate mitigation.	Same as collaborative robot.	ISO 10218-2 [12]
Collisions with robot arm	High (bruises, fractures, or equipment damage)	High (frequent interaction with moving robot arm)	Not acceptable; requires immediate mitigation.	Same as collaborative robot, but with a higher emphasis on monitoring and control due to higher speeds and forces.	ISO/TS 15066 [13]
Cutting hazard	High (severe cuts, lacerations, or amputations possible)	Medium (depends on handling and exposure to sharp edges)	Not acceptable; requires immediate mitigation.	Same as collaborative robot.	EN 12622 [15]
Crushing and shearing hazards	High (severe injuries possible)	Medium (depends on exposure and operational errors)	Not acceptable; requires mitigation.	Install guards and barriers to prevent access to crushing and shearing zones, use safety sensors to detect operator presence and stop machine movement and implement proper maintenance and inspection routines to ensure safety devices are functioning correctly.	EN 12622 [15]
Entanglement hazards	Medium (minor to severe injuries possible)	Medium (depends on presence of loose clothing or hair)	Not acceptable; requires mitigation.	Install guards and covers over moving parts to prevent entanglement, provide PPE such as hairnets and tight-fitting clothing and conduct regular safety training to highlight the dangers of entanglement.	EN 12622 [15]
Ejection of machine components	High (serious injuries possible)	Low (infrequent but serious when occurs)	Needs mitigation.	Securely fasten all machine components and perform regular inspections, use protective barriers to shield operators from potential ejected parts and implement maintenance protocols to identify and replace worn or damaged components.	EN 12622 [15]
Unexpected movement of machines	High (severe injuries or fatalities)	Medium (can occur due to control errors)	Not acceptable; requires immediate mitigation.	Same as collaborative robot.	ISO 10218-2 [12]
Impossibility of exiting robot cell for a trapped operator	High (fatalities possible)	Low (rare but critical)	Not acceptable; requires immediate mitigation.	Same as collaborative robot.	ISO 10218-2 [12]

RESULTS

The assessment of the mechanical hazards for collaborative and industrial robots reveals differences in risk severity, probability and mitigation measures. Collaborative robots generally have lower severity and probability ratings due to their design for safer human interaction. For example, pinch points have a high severity and medium probability for both robots, but collaborative robots use built-in safety sensors and lower speeds and loads, while industrial robots require more robust monitoring and control.

Collisions with the robot arm have a medium severity and high probability for collaborative robots, requiring mitigation through safety sensors, safety zones, speed and separation monitoring, and collision detection systems. Industrial robots with higher impact forces require similar measures, with an additional focus on monitoring and control, as they do not usually have built-in safety sensors, such as joint force and torque measurement. For this reason, more external safety features and mechanisms must be installed to reduce the risk to a tolerable level.

Cutting hazards are of high severity and medium probability for both robots, requiring guarding, safety sensors and PPE. Crushing and shearing hazards are significant for industrial robots, requiring guards and barriers, but are not as likely for collaborative robots. Entanglement hazards, which are of medium severity and probability, require similar mitigation for both types of robot, again with more emphasis on industrial robots.

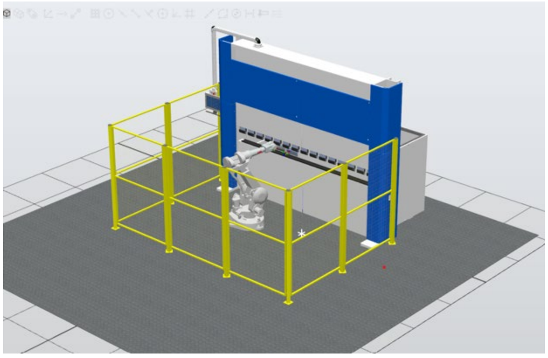

Figure 3: Suggestion of fencing with industrial robotic application.

Ejection of machine components and workpieces is a critical hazard for industrial robots, with high severity but low probability, which can be mitigated by securely mounting components, using protective barriers and implementing maintenance protocols. Unexpected movements of machines or robot cell parts are high severity, medium probability risks for both robots, requiring emergency stop functions, fail-safes and regular maintenance.

Finally, the risk of being trapped inside a robot cell is high severity but low probability for both types, and is mitigated by providing accessible emergency exits, ensuring that cell doors can be opened from the inside, and installing safety sensors.

In summary, while both types of robot share common risks and mitigation strategies, industrial robots often require more stringent safety measures due to higher operating forces and the lack of built-in torque and force control safety sensors. This highlights the need for tailored safety protocols to address the specific risks associated with each type of robot application. For the hazards and risks assessed from the industrial robot cell, fencing around the robot cell is suggested to ensure safe operation. This is shown in Figure 3. Partial fencing is also proposed for collaborative robotic cell to ensure that the area is not used for storage and accidental approach of operators and, for example, forklifts are better controlled.

It should also be noted that the risk protection measures are fully or partially achieved by the safety components controlled by a safety system. Standards 13849-1 and 13849-2 are required to assess the required performance of the electromechanical safety system [17, 18]. These results are only intended to give an example of risk assessment for collaborative and industrial robot solutions, and the final responsibility for risk assessment lies with the personnel responsible for their own solution.

CONCLUSION

From the results it can be concluded that the use of collaborative robots in machine tending applications still requires consideration of external safety features. Even if the collaborative robots are built with safety features such as force and torque sensors, the sharp edges of the workpiece or the robot tool still pose a hazard to the operator. However, the collaborative robot application in this application could be made safer because the collaborative robot has built-in safety features for force and torque monitoring of the robot joints. Using safety-rated laser area scanners in collaborative setups increases flexibility and safety by enabling dynamic safety zones and reducing the need for physical barriers. This makes the workspace more adaptable to change and improves productivity, particularly in low-volume production and mixed product assembly environments [19].

In the future, these applications will become more common as collaborative robotics presents a low barrier for workers to learn robot programming and overall machine usage. This article states that conducting a risk assessment for a collaborative robot, despite the novelty of the products, is feasible. Furthermore, in such applications, it is possible to achieve a higher level of safety more cost-effectively with a collaborative robot than with a standard industrial robot. Small and medium-sized enterprises (SMEs) in Europe, including Finland, often produce small series. This is due to the niche markets they serve, which typically require production in small batch sizes rather than large scale production [20]. The use of collaborative robots with machines where manual operation is still possible offers opportunities for companies specialising in customised products. Benefits of flexible and collaborative manufacturing processes make it important to investigate risk assessment examples to facilitate broader adoption of such applications.

ACKNOWLEDGEMENTS

The authors would like to thank the funder Regional Council of Southern Ostrobothnia of funding projects RoboValmis - Productivity for Manufacturing with Automation and Robotics (A78106) and ROHITVA - Robotic welding techniques in manufacturing SMEs (R-01026) where this application was first constructed and developed further. Also special thanks to Sedu Education Consortium for providing the machinery and software to make this article.

REFERENCES

1. McGrath, J. *Report on labour shortages and surpluses*. Publications Office of the European Union, 2021.
2. Tolpo, A. *Suomalaiset ammattilaiset katoavat jonnekin, mutta kukaan ei tiedä minne – metallifirmoilla on jäljellä vain yksi vaihtoehto [Finnish professinals disappear somewhere but nobody knows where – only one option remains for metal companies]*, Yle – Finnish Broadcasting Company, 30.1.2024.
3. Statistics Finland, *Teollisuuden myydyn tuotannon arvo 104,5 miljardia euroa vuonna 2022 [The value of the industry's sold production is 104.5 billion euros in 2022]*, release, 4.12.2023.
4. Hägele, M., Nilsson, K., Pires, J. N. Bischoff, R. Industrial robotics. *Springer handbook of robotics*, 2016, 1385-1422.
5. Internationald Federation of Robotics (IFR). *World Robotics 2023 Report*, 2023.
6. Lempiäinen, J. *Korjataan viime vuosikymmenen investointilamaa [Fixing the investment recession of the last decade], Automaatioväylä,* 28.12.2023, 22–25.
7. Liu, L., Guo, F., Zou, Z., Duffy, V. G. *Application, development and future opportunities of collaborative robots (cobots) in manufacturing: A literature review*, International Journal of Human–Computer Interaction, 40(4), 2024, 915-932.
8. Schumacher, S., Hall, R., Waldman-Brown, A., Sanneman, L. *Technology Adoption of Collaborative Robots for Welding in Small and Medium-sized Enterprises: A Case Study Analysis*, Proc. of the Conference on Production Systems and Logistics, 2022, 462-471.
9. Hentout, A., Aouache, M., Maoudj, A., Akli, I. *Human–robot interaction in industrial collaborative robotics: a literature review of the decade 2008–2017*. Advanced Robotics, 33(15-16), 2019, 764-799.
10. Malm, T. *Safety design process for collaborative robots*, VTT Technical Research Centre of Finland, VTT Research Report No. VTT-R-00062-22, 2022.
11. International Organization for Standardization (ISO). ISO 12100:2010. Safety of machinery — General principles for design — Risk assessment and risk reduction. Geneva: ISO; 2010.
12. International Organization for Standardization (ISO). ISO 10218-2:2011. Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration. Geneva: ISO; 2011.
13. International Organization for Standardization (ISO). ISO/TS 15066:2016. Robots and robotic devices — Collaborative robots. Geneva: ISO; 2016.
14. International Organization for Standardization (ISO). ISO 11161:2007. Safety of machinery — Integrated manufacturing systems — Basic requirements. Geneva: ISO; 2007.
15. European Committee for Standardization (CEN). EN 12622:2009+A1:2013. Safety of machine tools — Hydraulic press brakes. Brussels: CEN; 2013.
16. International Organization for Standardization (ISO). ISO/DIS 6909:2023. Machine tools Safety — Press brakes (Draft). Geneva: ISO; 2023.
17. International Organization for Standardization (ISO). ISO 13849-1:2015. Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design. Geneva: ISO; 2015
18. International Organization for Standardization (ISO). ISO 13849-2:2012. Safety of machinery — Safety-related parts of control systems — Part 2: Validation. Geneva: ISO; 2012.
19. Matheson, E., Minto, R., Zampieri, E. G. G., Faccio, M., & Rosati, G. (2019). Human–Robot Collaboration in Manufacturing Applications: A Review. Robotics, 8(4), 100. https://doi.org/10.3390/robotics8040100
20. European Commission. (2018). Cooperative foundries offer SMEs small-batch production. Retrieved from https://cordis.europa.eu/article/id/230809-cooperative-foundries-offer-smes-smallbatch-production