Institut de recherche
Robert-Sauvé en santé
et en sécurité du travail

Study of Machine Safety for Reduced-Speed or Reduced-Force Work

Yuvin Chinniah
Barthélemy Aucourt
Réal Bourbonnière

STUDIES AND RESEARCH PROJECTS

R-956

MECHANICAL AND PHYSICAL
RISK PREVENTION

OUR RESEARCH
is working for you !

The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), established in Québec since 1980, is a scientific research organization well-known for the quality of its work and the expertise of its personnel.

Mission
To contribute, through research, to the prevention of industrial accidents and occupational diseases and to the rehabilitation of affected workers;

To disseminate knowledge and serve as a scientific reference centre and expert;

To provide the laboratory services and expertise required to support the public occupational health and safety network.

Funded by the Commission des normes, de l'équité, de la santé et de la sécurité du travail, the IRSST has a board of directors made up of an equal number of employer and worker representatives.

To find out more
Visit our Web site for complete up-to-date information about the IRSST. All our publications can be downloaded at no charge.
www.irsst.qc.ca

To obtain the latest information on the research carried out or funded by the IRSST, subscribe to our publications:

- *Prévention au travail* the free magazine published jointly by the IRSST and the CNESST (preventionautravail.com)
- InfoIRSST, the Institute's electronic newsletter

Legal Deposit
Bibliothèque et Archives nationales du Québec
2017
ISBN : 978-2-89631-918-3
ISSN : 0820-8395

IRSST – Communications and Knowledge Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
publications@irsst.qc.ca
www.irsst.qc.ca

Study of Machine Safety for Reduced-Speed or Reduced-Force Work

Yuvin Chinniah[1], Barthélemy Aucourt[1],
Réal Bourbonnière[2]

[1]Polytechnique Montréal
[2]Consultation Réal Bourbonnière

STUDIES AND
RESEARCH PROJECTS

R-956

Disclaimer

Clic Research

A PDF version of this publication is available on the IRSST Web site.

This study was funded by the IRSST. The conclusions and recommendations are solely those of the authors.
This publication is a translation of the French original; only the original version (R-888) is authoritative.

PEER REVIEW
In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

ACKNOWLEDGMENTS

We would like to thank all the companies and individuals who took part in the study for allowing us to come and collect data. Without their willingness to help, we would not have been able to gather the field data required for the research.

We would also like to express our gratitude to Pascal Poisson, engineer and president of Intervention Prévention, for his extremely valuable contribution to this study, especially for having opened the doors to a number of companies for us. We would also like to thank all the members of the follow-up committee, particularly Khalid El Ahrache of the Association paritaire de santé et de sécurité du travail, secteur imprimerie et activités connexes (ASP Imprimerie) [sector-based OHS association for printshops] and Tony Venditti of the Association sectorielle – Fabrication d'équipement de transport et de machines (ASFETM) [transportation equipment and machinery manufacturing association], for their assistance.

ABSTRACT

The hazards associated with the moving parts of industrial machines are known to be the source of serious and even fatal accidents. The purpose of section 189.1 (previously 186) of the Quebec Regulation respecting Occupational Health and Safety (ROHS) is to provide guidance for machine maintenance, repair and adjustment work, further to section 182, which governs production work by prohibiting access to hazard zones and ensuring that moving parts are stopped when workers enter these zones. The focus of this research project was the application of ROHS section 186. The first objective was to assess the state of knowledge and recommendations in the literature on reduced-energy modes of operation, especially in terms of speed, force, pressure and temperature values. The second objective was to understand, through factory visits, how ROHS section 186 is being implemented.

A review of the literature revealed a wide variety of recommendations with respect to reduced-energy levels. The recommendations, chiefly based on standards and closely related to a specific context, are generally presented with accompanying supplementary conditions. A reduction in energy alone is often not sufficient to reduce the risk. Factory visits have shown that the various conditions prescribed in ROHS section 186 are sometimes hard to meet simultaneously. Safeguards, including the reduction of energy levels, are therefore a compromise between different constraints (related to job needs, the machine itself, production requirements, etc.) and risk reduction in order to prevent or reduce potential harm.

Last, the study revealed that reduced-energy values depend on many factors and that the wide variety of possible situations makes it necessary to conduct an in-depth risk analysis. The application of ROHS section 186 is therefore an integral part of the risk assessment and reduction process for tasks where workers have no alternative but to enter the zone where machine parts are in motion. The purpose of this process is to achieve a level of risk comparable to that contemplated in ROHS section 182, by taking protective measures that will compensate for opening a guard or starting up the machine. These protective measures are based on three principles: reduce harm, increase the possibility of avoiding harm and reduce exposure to the hazard. Yet the issue of determining reduced-energy levels remains unresolved. Generally speaking, when the literature recommends values, if the situation in question corresponds exactly to the context described in the literature, then designers may use these same values. On the other hand, when no reference is available, the determination of a tolerable energy level must be based on more extensive thought and analysis. Only a thorough comparison of the context of the proposals made in the literature and that of the real situation will allow extrapolation of the recommendations to comparable, but not identical situations. A risk analysis must be conducted. The study identified some reference points or factors that will provide guidance to designers and users as they analyse specific cases and try to decide on the most appropriate values for reduced speed, force, kinetic energy and contact pressure.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Every year in Quebec a number of serious and fatal accidents occur when people are working on machines. According to a study by the Commission de la santé et de la sécurité du travail (CSST) [occupational health and safety board] [1], most injuries are caused by moving parts. Between 2008 and 2011, there were an average of 11 machinery-related deaths per year in Quebec. Of those, 3.2 (about 30%) were caused by access to moving parts. While those figures have been declining in recent years, the CSST has had a zero-tolerance policy on access to moving parts since 2005, because the number is still high.

In an accident in 2013 [2], a worker was killed when she unjammed a trolley at the entrance to a shot-blasting machine. Unjamming the trolley restarted the overhead conveyor and the worker got caught between the next trolley and the open doors of the shot-blasting machine. The small amount of clearance and the conveyor speed of 230 mm/s combined to trap the victim within six seconds, because she couldn't get out of the way. The CSST determined the causes to be (1) an easily accessible drawing-in and entrapment zone, (2) the unjamming that exposed the victim to the hazards of being drawn in and entrapped, and (3) inadequate occupational health and safety management with respect to unjamming the shot-blasting machine (underestimated risk, poor communication of new work procedures). Without judging whether or not it was necessary to enter the hazard zone while parts were moving, this example illustrates the fact that even a reduced speed may not be low enough and that additional safeguards must be provided.

Situations in which workers have access to moving parts to perform a task are fairly common. By conducting an in-depth risk analysis, it is possible to determine the needs of the task and appropriate risk-reduction measures. In the example above, movement of the hazardous parts involved could and should have been stopped.

Figure 1 shows the root-cause analysis of another accident, this one involving a flattening machine in France. It is taken from the EPICEA database (file number 17737) [3].[1]

1. EPICEA is an anonymous national database of more than 18,000 workplace accidents involving employees covered by the general social security program that have occurred in France since 1990. The accidents may be fatal, serious or significant in terms of prevention.

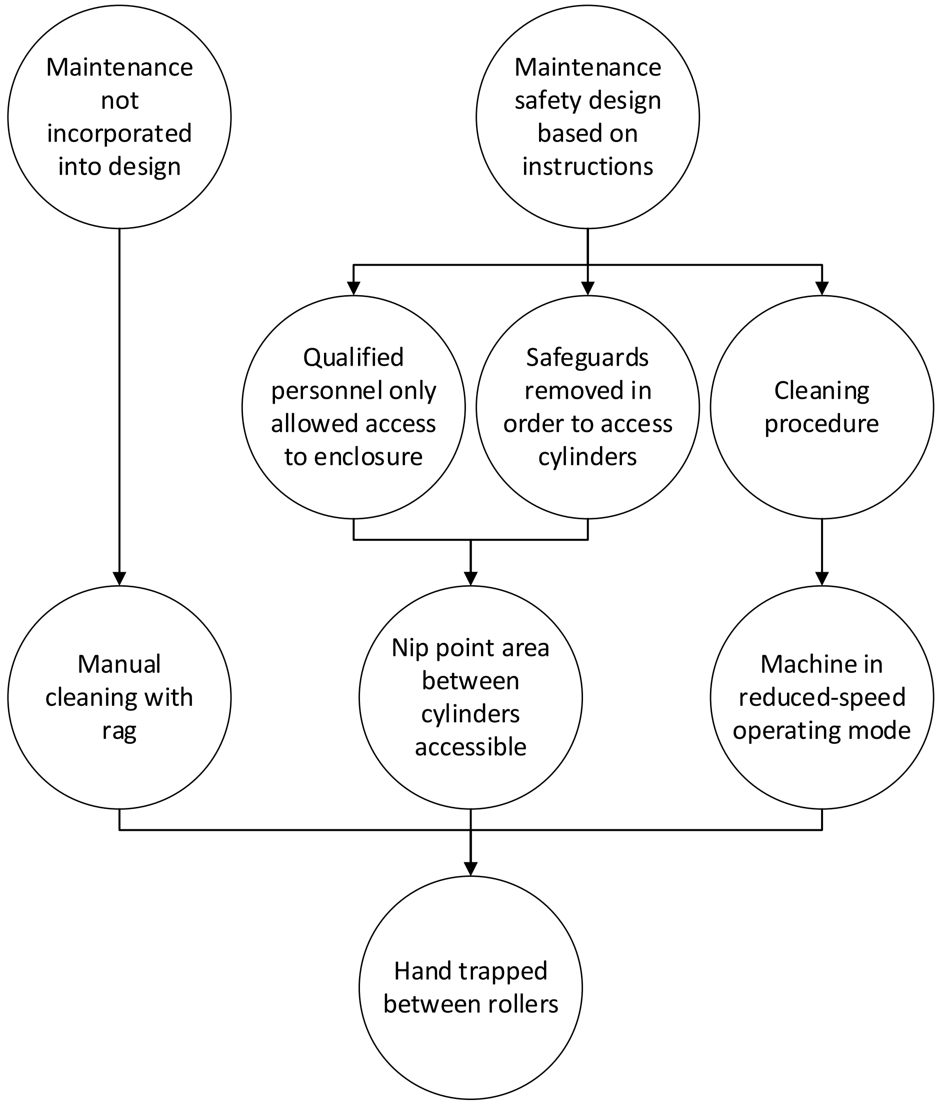


Figure 1 – Root-cause analysis of accident involving a flattening machine, from EPICEA database.

According to the accident description, the machine was running at reduced speed. The operator had followed the established procedure and reduced the speed from 1,000 mm/s (60 m/min) to 167 mm/s (10 m/min). But that was not enough to prevent the accident. The machine was still in continuous operation.

Section 186 of Quebec’s ROHS states [4]:

> When a worker must access a machine’s danger zone for adjustment, unjamming, maintenance, apprenticeship or repair purposes, including for detecting abnormal operations, and to do so, he must move or remove a protector, or neutralize a protective device, the machine shall only be restarted by means of a manual control or in compliance with a safety procedure specifically provided for allowing such access. This manual control or this procedure shall have the following characteristics:

(1) it causes any other control mode or any other procedure, as the case may be, to become inoperative;

(2) it only allows the operation of the dangerous parts of the machine by a control device requiring continuous action or a two-hand control device;

(3) it only allows the operation of these dangerous parts under enhanced security conditions, for instance, at low speed, under reduced tension, step-by-step or by separate steps.

It is worth noting that the third point requires operation “at low speed” or “under reduced tension” [i.e., force]. That was the case in the second accident example above, but neither of the other conditions of the section was met.

In the first example (shot-blasting machine), the overhead conveyor was advancing at a rate of 230 mm/s, which was too fast for the victim to avoid getting hurt. Yet a speed of 230 mm/s is close to the 250 mm/s recommended and deemed safe in standards respecting robots.

The following questions therefore come to mind: Why is it adequate in one case, but not the other? What is reduced speed or force? What parameters should be taken into account in determining the right reduced speed or force? These questions must be answered by the manufacturers as well as the users of industrial machinery.

The aim of this report is to review the reduced-energy values used in the literature, but also in companies. The report also looks at the conditions of working on machines running in reduced-energy mode. Prescribed operating conditions and those observed during factory visits will also be discussed.

The objectives of the study and the research method used will first be described. The theoretical results taken from the literature (threshold values of speed, force, etc., and measures guiding work in such circumstances) will then be presented, along with our findings on company visits. Third, an analysis of the theoretical and practical results of the preceding parts will be done with a view to interpreting the data, comparing them and extracting relevant information for deciding on reduced-energy values. The results analysis will also allow us to determine strong points and those requiring further study.

2 RESEARCH OBJECTIVES

The primary objective of this study was to review the knowledge of *reduced-energy* operating modes and recommendations on standard practices in the field. That includes a characterization of the energy levels of various hazards: mechanical (speed and force), thermal (temperature), hydraulic and pneumatic (pressure).

The second objective was to gain a better understanding of how ROHS section 186 is being implemented, by making company visits and observing work on a variety of machines.

3 METHOD

3.1 Literature

In order to achieve our first objective, we conducted an extensive review of the literature. We started with the standards and guides for the four types of machines initially targeted for factory visits (robots, machining equipment, printing presses and paper-making machines). The references cited in those sources were consulted. The Compendex database was used to search scientific references (keywords: low speed, reduced speed, safe speed, limited speed, reduced force, limited force, reduced force, safe force, machine contact pressure, reduced energy, maintenance and safety, robot safety, printing press, paper-making machine, conventional lathe, numerically controlled lathe, hold-to-run control, maintenance control mode, low-speed cleaning, robot programming, robot learning mode, and their French equivalents). The reference documents selected for review were classified by type (see table 1).

Table 1 – Type and number of reference documents used in research.

TYPE	NUMBER[2]
Standard	51
Guide	14
Scientific paper	11
Research report	2

First, all excerpts containing relevant information were put together in an Excel spreadsheet to provide an overall picture of the review of the literature. This enabled us to extract important concepts, then analyse and sort them by category (e.g., recommended value, hazards involved, other safeguards, etc.). The theoretical results based on the data are discussed in detail in section 4.1.

3.2 Company Visits

The method used to achieve the second objective was to visit a variety of companies with a view to

- Understanding and characterizing the situations in which work is done with reduced energy
- Noting and measuring, if possible, the reduced-energy values used
- Understanding the choices made and identifying the references used by companies
- Determining the factors that influence the choice of values; in other words, the reasons for their use

2. They are not all necessarily listed in the bibliography. When several versions of the same standard contained identical recommendations, only the most recent was included.

It is important to note that the purpose was not to judge the appropriateness or validity of recommendations in the literature, nor to identify work actually covered by section 186, but rather to observe how companies apply the regulation.

The method used for the visits included these steps:

1) **Selection and contact with companies**

The members of the follow-up committee, in particular ASP Imprimerie and the ASFETM, as well as the firm Intervention Prévention, helped the research team select companies and make contact with them. We also contacted companies that had collaborated on other activities or research projects in the past. The literature provided when making contact (introductory brochure, see Appendix A, and covering letter, see Appendix B), contained the following information, which was needed to select machines and work of interest for our study:

- Project overview (issues, objectives)
- Needs of study (particularly concerning field observations)
- Selection criteria for situations to observe
  - The hazard zone had to be limited to a defined area and normally made inaccessible by means of a guard (fixed or mobile) or a protective device (safety light curtain, pressure-sensitive mat, etc.).
  - The work to be done was required for needs other than normal production, such as to make repairs or adjustments or look for faults.
  - The machine's speed or force (energy) had to be reduced so as to be the primary means of risk reduction, allowing the worker to do the job safely.
- Details of structure of visit (allowing employers to anticipate the employees needed for the visit, for instance)

Companies had to have one or more machines that needed work in hazard (danger) zones. These situations had to reflect the context described in ROHS section 186: a worker must access a machine's danger zone for adjustment, unjamming, maintenance, apprenticeship or repair purposes while it is running. Work for production purposes was excluded. In accordance with the provisions of section 186, workers could use control devices mentioned in the regulation, such as a control device requiring continuous action or a control device for operation by separate steps (i.e., inching/jogging control).

2) **Development of data collection form**

A data collection form (see Appendix C for the final version) was developed to gather relevant, comparable information when visiting companies. The information mainly concerned the conditions described in ROHS section 186, as well as other points identified from the review of the literature. Two preliminary visits enabled us to fine-tune the initial version and test the changes. The form includes these points:

- Part A – Contact and characterization of tasks (in meeting room)
  - Identify plant and representatives

    - Identify work that needs to be done while machine running, with accessible hazards
    - Characterize reasons and requirements for work
    - Note history of accidents and incidents involving the machine, and see whether they occurred when it was in reduced-energy operating mode
- Part B – Study of reduced-speed/force mode (in meeting room)
    - Identify the default or adjusted speeds and/or force levels of the machine
    - Identify companies' needs (why was a certain mode added, situation with regard to standards and regulations)
    - Understand adjustments and constraints determining these choices (based on the literature, experience, taking into account time and costs, etc.)
- Part C – Machine/hazard zone studied and observation of work done at reduced speed/force (in plant)
    - Identify all existing and disabled means of risk reduction
    - Observe and characterize conditions of work (spatial organization of work area, PPE used, type of access to hazard zone, control device used, visibility of hazard zone, etc.)
    - Identify risks
- Part D – Testing (in plant)
    - Carry out tests to fill in this part of form
    - Determine the effects of various protective devices through functional testing
    - Measure speed, force, temperature, etc., if possible
    - Examine points specific to certain machines (identified in the literature)
- Part E – Technology used (in plant)
    - Identify technical means used to reduce and maintain speed, force, energy at a safe level once reduced-speed/force mode selected (for example, by limiting power or adjusting machine's programming, category of control system)
    - Identify checking mechanisms in place (exists or not, type of indicator)

3) Collection of information at companies

In all, 15 work situations on the same number of machines were studied at nine different companies. Appendix D describes a typical half-day company visit. Visits were organized around the data collection form. An OHS officer accompanied the visiting researcher or researchers and answered questions. When necessary, the OHS officer asked an engineer, maintenance technician or operator to fill in parts A and B. For parts C, D and E, an operator or maintenance technician was needed to perform the work to be observed and to do the functional testing of protective devices when possible. The research team asked questions either before or after the work was done, so as not to distract the worker. When permitted, the researchers took photos and video to supplement the information collected on the data form.

4) Data compilation and analysis

After the visits, the data gathered was compiled in an Excel spreadsheet and organized by topic (see sections of data collection form) to check that all the relevant data had been collected and to facilitate the qualitative analysis. This enabled us to identify the information characterizing the work covered by ROHS section 186 and how it was performed.

4 RESULTS

4.1 Findings from the Literature

4.1.1 Quebec, Canadian and International Regulations

Section 182 of the ROHS sums up the spirit of the regulation and states that all the danger zones of a machine must be made inaccessible, failing which the machine must be equipped with at least one guard or protective device to make it safe for workers. Section 186 proposes an alternative for situations in which some work, not considered to part of normal operations, must done while the machine is running. This section seems to have been inspired by European standards published before the Quebec regulation was enacted in 2001 and in which these recommendations were included in the context of enhancing worker safety by anticipating workplace realities and adapting machines' control systems accordingly [5]. The approach taken in section 186 is consistent with current standards and is presented in standard ISO 12100 [6], most recently updated in 2010:

> *6.2.11.9 Control mode for setting, teaching, process changeover, fault-finding, cleaning or maintenance.*
> *Where, for setting, teaching, process changeover, fault-finding, cleaning or maintenance of machinery, a guard has to be displaced or removed and/or a protective device has to be disabled, and where it is necessary for the purpose of these operations for the machinery or part of the machinery to be put into operation, the safety of the operator shall be achieved using a specific control mode which simultaneously*
>
> *a) disables all other control modes,*
> *b) permits operation of the hazardous elements only by continuous actuation of an enabling device, a two-hand control device or a hold-to-run control device,*
> *c) permits operation of the hazardous elements only in reduced-risk conditions (for example, reduced speed, reduced power/force, step-by-step, for example, with a limited movement control device), and*
> *d) prevents any operation of hazardous functions by voluntary or involuntary action on the machine's sensors.*
>
> *NOTE: For some special machinery other protective measures can be appropriate.*
>
> *This control mode shall be associated with one or more of the following measures:*
>
> - *restriction of access to the danger zone as far as possible;*
> - *emergency stop control within immediate reach of the operator;*
> - *portable control unit (teach pendant) and/or local controls (allowing sight of the controlled elements).*
>
> *See IEC 60204-1.*

The essence of these recommendations can also be seen in many normative or legal documents used in Europe. For instance, the French Labour Code, directly modelled on standard EN 292-2/A1:1995 [5], which also provided the basis for standard ISO 12100 [6], takes a similar approach, especially in section 1.2.5, respecting the operating mode selection mechanism, which says:

> The control mode selected must override all other control systems with the exception of the emergency stop. If machinery has been designed and built to allow for its use in several control or operating modes presenting different safety levels (e.g. to allow for adjustment, maintenance, inspection, etc.), it must be fitted with a mode selector which can be locked in each position. Each position of the selector must correspond to a single operating or control mode. The selector may be replaced by another selection method which restricts the use of certain functions of the machinery to certain categories of operator (e.g. access codes for certain numerically controlled functions, etc.). If, for certain operations, the machinery must be able to operate with its protection devices neutralized, the mode selector must simultaneously:
>
> – disable the automatic control mode,
> – permit movements only by controls requiring sustained action,
> – permit the operation of dangerous moving parts only in enhanced safety conditions (e.g. reduced speed, reduced power, step-by-step, or other adequate provision) while preventing hazards from linked sequences,
> – prevent any movement liable to pose a danger by acting voluntarily or involuntarily on the machine's internal sensors.
> – In addition, the operator must be able to control operation of the parts he is working on at the adjustment point.

This machinery risk reduction technique is also found in the European Directive on Machinery [7], in particular subsection 1.2.5 on the selection of control or operating modes, which states:

> If, for certain operations, the machinery must be able to operate with a guard displaced or removed and/or a protective device disabled, the control or operating mode selector must simultaneously:
>
> – disable all other control or operating modes,
> – permit operation of hazardous functions only by control devices requiring sustained action,
> – permit the operation of hazardous functions only in reduced-risk conditions while preventing hazards from linked sequences,
> – prevent any operation of hazardous functions by voluntary or involuntary action on the machine's sensors.

Like European standards and French regulations, the Quebec regulation makes it mandatory to change working conditions in a hazard zone during machine operation, so as to reduce the risk to workers. Yet the European Directive on Machinery is very vague about how to provide "reduced-risk conditions." On the other hand, ROHS section 186 and the French Labour Code spell out more precise concepts: low/reduced speed, reduced tension (force), separate-step operation (inching/jogging). Under the ROHS, the safety of workers who must perform work while a machine is running is ensured by section 182. The types of activity given as examples in section 186—adjustment, unjamming and maintenance—show that tasks usually performed for production purposes are excluded. ROHS section 186 therefore seeks to make "unusual" tasks (those outside regular production) safer. A reading of the European regulations shows, on the contrary, that whatever the task, if it requires access to a hazard zone with moving parts, the machine must comply with all the requirements cited above.

4.1.1.1 Risk Reduction

Type A standards, which define the basic concepts and general design and use principles for machines and components, also take up the concept of work *in reduced-risk conditions (reduced speed, reduced power/force, step-by-step, for example, by means of a limited movement control device)* [6]. Standard ISO/TR 14121-2 recommends *reducing energy (for example, lower force, lower hydraulic/pneumatic pressure, reduced working height, reduced speed)* [8] as a means of risk reduction by design by stating that *if the hazard cannot be eliminated by design, it should be reduced.*

One important characteristic of the risk reduction methods proposed by the standards and regulations is the reliance on reducing energy levels, yet none of the above-mentioned regulations gives precise energy-limit values that would ensure worker safety.

Despite the fact that the term “enhanced security conditions,” or even the concept of reduced speed and force, is not very precise, it seems that ROHS section 186 has the same risk-reduction objective as section 182. It is assumed that risk must be reduced as far as possible, down to a level comparable to what would be achieved by a strict enforcement of the provisions of section 182. Under this interpretation, moving or removing a guard, or neutralizing a protective device, must therefore be offset by the measures required in section 186 to achieve a level of risk comparable to that mentioned in section 182.

4.1.1.2 Operating Modes and Harm Avoidance

Used solely as a risk reduction principle, energy limitation or the displacement of hazardous parts does not always offer absolute protection. This principle must be combined with other measures that either limit exposure to the hazard or increase the worker’s ability to avoid any potential harm resulting from contact with the hazard. The machine must therefore be designed to allow this operating mode, which is hereafter referred to as “reduced-speed and/or force mode.” According to the normative and regulatory recommendations discussed above, this operating mode, when selected, should disable all other operating modes. In other words, it must override any other control, with the exception of emergency stop devices, which must, of course, remain functional at all times.

Furthermore, machines cannot be restarted without the use of a hold-to-run control by the worker. The three main principles that the reduced-speed and/or force mode must follow under the above-mentioned regulations are summarized in table 2.

Table 2 – Recap of regulatory requirements for reduced-speed and/or force mode.

– Overrides any other control except emergency stops – Requires use of a hold-to-run control – Does not allow operation of hazardous parts except under enhanced security conditions (e.g., reduced speed, reduced force) – Any voluntary or involuntary action on a machine's sensors must not trigger movement of hazardous parts

Only ROHS section 186 does not include the fourth requirement concerning voluntary or involuntary action on a machine's sensors.

4.1.2 Reduced Speed

Table 3 lists all reduced-speed values from the literature, expressed in millimetres per second (mm/s), in ascending order, with references to the documents from which the values were taken.

Table 3 – Low/reduced speed values from the literature, in ascending order, with references.

INDUSTRY	MACHINES – MACHINE PART (if specified)	PRESCRIBED SPEED* (mm/s)	SOURCE
Printing	Printing press	8	[9]
Printing	Sheet-printing press and varnishing machine	8	[10]
Printing	Printing and paper converting machine – Embosser	8	[11]
Printing	Corrugator – Double-face gluer Folder-gluer Online machine – Feeder Auto-feed platen press – Feeder	8	[12]
Printing	Embosser	8	[13]
Manufacturing	Hydraulic press brake	10	[14]
Manufacturing	Press	10	[15]
Manufacturing	Hydraulic press brake	10	[16]
Manufacturing	Hydraulic press brake	10	[17]
Manufacturing	Hydraulic press brake	10	[18]
Textile industry	Weaving machine	10	[19]
Manufacturing	Integrated manufacturing system	10	[20]
Manufacturing	Plastic injection molding machine	10	[21]
Printing	Printing press	17	[9]
Printing	Binding and finishing system[3]	17	[13]
Printing	Printing and paper converting machine – Common requirements	17	[22]
Industrial robots	Robot	17	[23]
Pulp and paper	Winder	17	[24]
Manufacturing	Plastic injection molding machine	25	[25]
Manufacturing	Plastic injection molding machine	30	[21]
Printing	Printing press	33	[9]

INDUSTRY	MACHINES – MACHINE PART (if specified)	PRESCRIBED SPEED* (mm/s)	SOURCE
Textile industry	General – Parts with rollers (nip points) Winding machine	33	[26]
Manufacturing	High-speed machining centre	33	[27]
Printing	Unwinder/rewinder	33	[22]
General	Integrated manufacturing system	33	[20]
Manufacturing	Machining centre	33	[28]
Printing	Printing press	50	[9]
Printing	Guillotine cutter	50	[29]
Printing	Rotary printing press and varnishing machine	50	[10]
Printing	Straight guillotine cutter – Paper end stop	50	[30]
Printing	Paper-converting machine – Lengthwise folding unit	50	[11]
Manufacturing	High-speed machining centre	67	[27]
Pulp and paper	Cutter – Unwinding unit	80	[31]
Printing	Printing press	83	[32]
Printing	Embosser – Rolls, backing rolls, laminating rolls	83	[13]
Printing	Printing and paper converting machine – Common requirements Unwinder/rewinder	83	[22]
Printing	Printing press (with varnishing sheets)	83	[10]
Printing	Horizontal rotary bobbin unwinder Litho-laminators	83	[11]
Printing	Corrugator – Preheater	83	[12]
Manufacturing	Machining centre	83	[28]
Printing	Envelope-making machine – Printer group	100	[11]
Printing	Corrugator, single-sided	100	[12]
Printing	Rotary printing press and varnishing machine	133	[10]
Manufacturing	Machining centre	133	[28]
Printing	Printing press	167	[9]

INDUSTRY	**MACHINES – MACHINE PART (if specified)**	**PRESCRIBED SPEED* (mm/s)**	**SOURCE**
Printing	Binding and finishing system	167	[13]
Textile industry	Textile industry – Gill box	167	[33]
Printing	Glue binder machine	167	[11]
Industrial robots	Robot	170	[34]
Industrial robots	Robot	200	[35]
Pulp and paper	Calender	200	[36]
Industrial robots	Robot	250	[37]
General	General	250	[38]
Industrial robots	Robot	250	[39]
Manufacturing	Integrated manufacturing system	250	[20]
Textile industry	Air transportation of processed materials	250	[26]
General	General	250	[8]
Printing	Corrugator – Splicer	250	[12]
Pulp and paper	Paper making and finishing machine – General requirements	250	[40]
Pulp and paper	Cutter	300	[31]
Printing	Printing press	330	[9]
Mining	Roof bolter	330	[41]
Printing	Unwinder/rewinder	330	[22]
Printing	Hardcover book production line	330	[11]
Printing	Corrugator – Stacker	1500	[12]

*The prescribed speeds are linear (speed of an object in translational motion or peripheral speed of a rotating object).

Figure 2 shows the breakdown of industries (or types of machines) by number of references to reduced-speed and/or force mode (in both qualitative terms and precise values; the same value may be counted several times in the same document). Robots and machine-tools that may be used in several industries are considered independently.

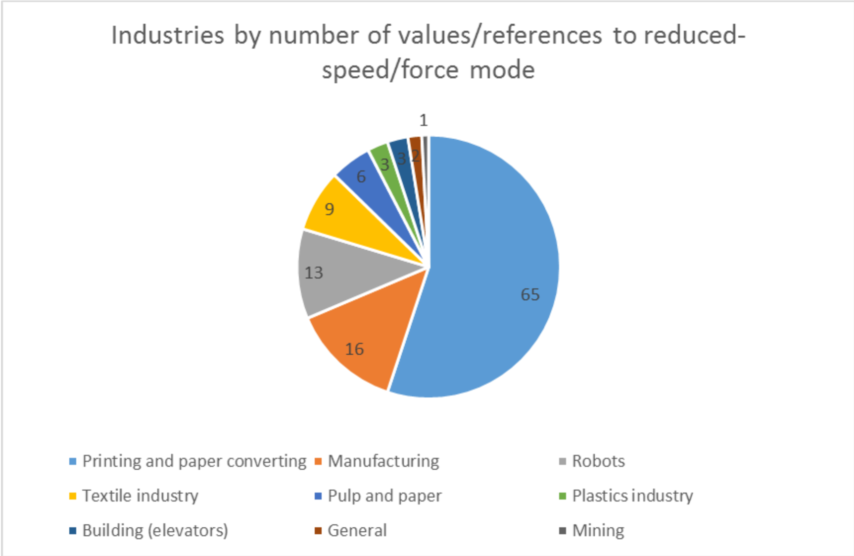


Figure 2 – Industries/types of machines by number of values/references to reduced-speed/force mode.

It can be seen that the printing and paper-converting industry has by far the most recommendations (65/118, or 55%). This industry uses a multitude of different machines (sheet-fed presses, rotary presses, guillotine cutters, rewinders, unwinders, etc.) that require frequent work on them. Manufacturing, as well as machine-tools and robotics, are also fairly well documented (16/118 and 13/118, or 14% and 11%, respectively). If machinery and not the actual industry are considered, robots are the machines about which the most information on reduced-speed operation is available.

4.1.3 Reduced Force

Table 4 lists all reduced-force values from the literature, expressed in newtons (N), in ascending order, with references to the documents from which the values were taken.

Table 4 – Force values from the literature, with references.

AREA	MACHINE – MACHINE PART – HAZARD	PRESCRIBED FORCE (N)	SOURCE*
Printing	Manual-feed platen press	20	[12]
Printing	Printing press	50	[32]
Printing	Binding and finishing system – Movable guards	50	[13]
Printing	Printing press – Motorized movable guards	50	[10]
Printing	Wire-stitching machine, riveting machine, eyeletting machine, stapling machine (manual feed) Saddle stitcher Envelope-making machine – Conveyor with separating disks	50	[11]
Printing	Folder-gluer – Traction belt	70	[12]
General	General	75	[41]
General	General	75	[42]
Printing	Folder-gluer – Press zone	100	[12]
Building	Elevator – Door	135	[44]
General	General	150	[42]
Printing	Printing press	150	[32]
Printing	Binding and finishing system	150	[13]
General	General	150	[43]
General	General – Movable guards	150	[45]
Printing	Printing press – Motorized movable guards Screen-printing machine	150	[10]
Printing	Directory-printing and -cutting machine	150	[30]
Printing	Corrugator – Double-face gluing device	150	[12]
Building	Elevator – Horizontally sliding automatic doors	150	[46]
Pulp and paper	Paper making and finishing machine – Prescriptions against crushing hazard	150	[40]
Printing	Gluing laminating machine	200	[11]
Printing	Binding and finishing system – Counter-stacker	200	[13]
Printing	Printing press	300	[9]
Printing	Corrugator – Splicer Online machine – Feeder	300	[12]

AREA	MACHINE – MACHINE PART – HAZARD	PRESCRIBED FORCE (N)	SOURCE*
Printing	Binding and finishing system	300	[29]
Printing	Paper cutting machine	300	[47]
Printing	Unwinder/rewinder	300	[22]
Printing	Screen-printing machine	300	[10]
Printing	Paper cutting machine – Paper press	300	[30]
Printing	Binding and finishing system	500	[29]
Printing	Straight guillotine cutter	500	[47]
Printing	Paper cutting machine – Paper press Paper cutting machine – Built-in feeder and receiving device	500	[30]
Printing	Folder-gluer – Press zone	500	[12]

*As sources may cover several machines or variations on machines, some may recommended the same value several times.

4.1.4 Reduced Kinetic Energy

Table 5 lists all reduced-kinetic energy values from the literature, expressed in joules (J), in ascending order, with references to the documents from which the values were taken.

Table 5 – Kinetic energy values from the literature, with references.

AREA	MACHINE – MACHINE PART – HAZARD	PRESCRIBED ENERGY (J)	SOURCE*
Building	Elevators – Door	3.5	[44]
General	General	4	[42]
General	General	4	[43]
General	General – Movable guards	4	[45]
Building	Elevator – Door	4	[46]
General	General	10	[42]
General	General	10	[43]
General	General – Movable guards	10	[45]
Building	Elevator – Door	10	[46]

*As sources may cover several machines or variations on machines, some may recommended the same value several times.

4.1.5 Reduced Pressure

Table 6 lists all reduced-pressure values from the literature, expressed in newtons per square centimetre (N/cm^2), in ascending order, with references to the documents from which the values were taken.

Table 6 – Pressure values from the literature, with references.

Area	Machine – Machine part – Hazard	Prescribed pressure (N/cm²)	Source*
General	General Packaging machines	10	[52] [53]
General	General Packaging machines	20	[52] [53]
Packaging	Strapping machine	25	[48]
Packaging	Group and secondary packaging machines	25	[59]
General	General Packaging machines	25	[52] [53]
General	General Packaging machines	30; 35; 45	[52] [53]
General	General	50	[42]
	Group and secondary packaging machines	50	[59]
General	General Packaging machines	50	[52] [53]
General	General Packaging machines	60; 70; 75; 80	[52] [53]

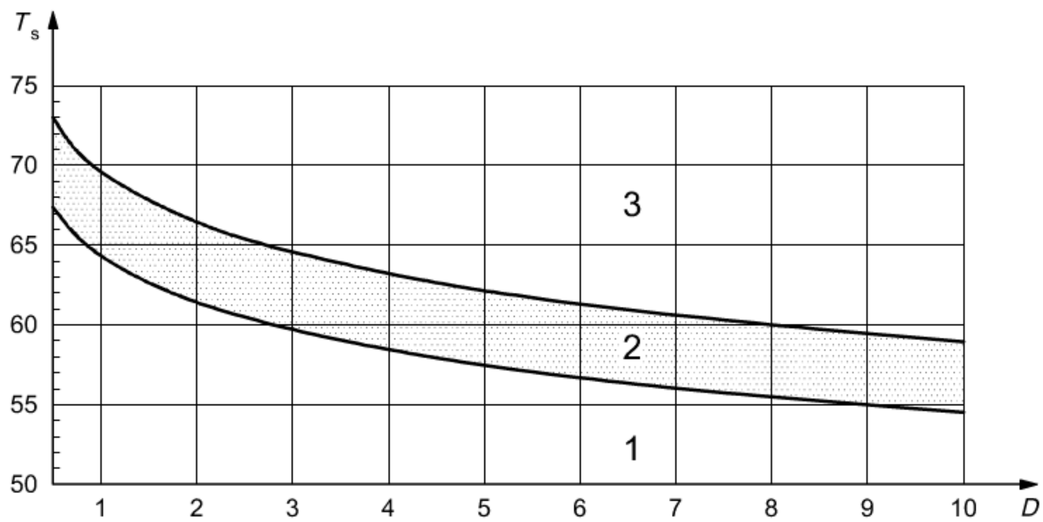
*As sources may cover several machines or variations on machines, some may recommended the same value several times.

4.1.6 Reduced Thermal Energy

The temperature of a machine part is, of course, a hazard that can cause serious injuries to workers. Like other forms of energy discussed so far, reducing the temperature of hazardous parts can be considered an effective way to reduce risk.

Standard ISO 13732-1 [49] gives temperature thresholds that can cause burns when a person's skin is in contact with a hot surface for 0.5 seconds or more.

As shown in figure 3, temperatures and exposure times are defined and can be used to determine precisely the risks to which workers may be exposed. Although no example was found in the literature, lowering the temperature could easily be used as a means of reducing risk within the application of ROHS section 186 and consistent with the information in standard ISO 13732-1.



Key

D contact period, s

T_s surface temperature, °C

1 no burn

2 burn threshold

3 burn

Figure 2 — Burn threshold spread when the skin in contact with hot, smooth surface made of bare (uncoated) metal

Figure 3 – Burn threshold value chart taken from standard ISO 13732-1.[3]

4.1.7 Specific Studies to Determine Reduced Energy Values

4.1.7.1 Determining Safe Reduced Speed for Robots

The review of the literature found two studies (Beauchamp et al. [34], Kuivanen et al. [50]) that sought to determine a safe reduced speed for robots.

They both used a similar protocol: the subject was inside the robot's enclosure and performed a task to simulate some kind of work. The robot executed a program containing intentional "errors" that could occur randomly. The subject's reaction time in detecting and responding to the simulated problem or impact was then measured in terms of several parameters: illumination level, luminance contrast between the robot and its background, in Beauchamp et al.; the motion speed of the robot and the subject's position in relation to the robot at the time of the problem in both Beauchamp et al. and Kuivanen et al.

3. Excerpts from standard ISO 13732-1: 2008, *Ergonomics of the thermal environment – Methods for the assessment of human responses to contact with surfaces – Part 1: Hot surfaces*, are reproduced here with the permission of AFNOR. Only the full original text of the standard, as distributed by AFNOR Éditions—available online from www.boutique.afnor.org—has the authority of a standard.

Beauchamp et al. concluded that the speed of 250 mm/s recommended in the standards is only valid if the worker uses a teach pendant equipped with a dead-man switch (robot stops moving when switch released). Yet, at the time the paper on that study was written (1991), very few teach pendants had switches like that. The authors therefore recommended a reduced speed of 170 mm/s, based on their results.

As for Kuivanen et al., their results show that the number of collisions increases significantly at speeds above 150 mm/s. Depending on the operating mode, the operator does not control the robot permanently (when not using a teach pendant). They therefore likewise concluded that the recommended speed of 250 mm/s should be reduced and that the new recommendation should be based on studies that take into account a human being's ability to detect and avoid a potential collision with a robot.

Only one study designed to determine a mathematical collision model that would make it possible to limit the need for long, expensive experimental studies was found [51]. In that study by Park et al., data from simulations of head and chest impacts with a robot were compared with experimental data (obtained with a model, or a dead body in the case of an impact to the nose). The contact surface used was blunt. The remaining variable that came into play in determining a safe speed was the mass of the robot arm assembly and load. Although the purpose of the paper was different, it is nevertheless clear that the maximum safe speed would differ from one robot to the next because of differences in mass. Park et al. concluded that the mathematical model is relatively reliable and can be used to study passive safety mechanisms (in other words, those not requiring any human intervention, such as an air bag in a motor vehicle, in contrast with an emergency stop button, for instance), or for safety control systems. In addition, Park et al. noted that major injury, such as a fracture of the nose, thyroid or cricoid cartilage, could occur with most industrial robots (except if the mass of the arm and load is less than 4 kg).

4.1.7.2 Determining Forces and Surface Pressure Limits Acceptable to Human Body

The Institute für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA) conducted an experimental study to estimate the resistance limit values of the different parts of the human body [52]. The measurements were carried out on a model having resistance and deformation properties similar to those of the human body. The criteria used to determine whether a human body would have been injured correspond to the deformation undergone by the model at the time of impact. The results of the study are reproduced in Appendix B of standard NF EN 415-10 [53] and presented in table 7.

Table 7 – Table taken from standard NF EN 415-10 on crushing force, impact force and static surface pressure limits acceptable to the human body.[4]

Parts of the body		Details of parts of the body	Crushing force [N]	Impact force [N]	Static pressure at surface of body [N/cm²]
1. Head and neck	1.1	Skull/forehead	130	175	30
	1.2	Face	65	90	20
	1.3	Neck (sides/back)	145	190	50
	1.4	Neck (front/larynx)	35	35	10
2. Trunk	2.1	Back/shoulders	210	250	70
	2.2	Ribcage	140	210	45
	2.3	Stomach	110	160	35
	2.4	Pelvis	180	250	75
	2.5	Buttocks	210	250	80
3. Arms	3.1	Arm/elbow joint	150	190	50
	3.2	Forearm/wrist joint	160	220	50
	3.3	Hand/finger	135	180	60
4. Legs	4.1	Thigh/knee	220	250	80
	4.2	Lower leg	140	170	45
	4.3	Feet/toes/joints	125	160	45

The results show that the acceptable limits vary with the area of the body in question and that acceptable impact (dynamic) forces are always higher than or equal to crushing (static) forces.

4.1.8 Complementary Means of Risk Reduction

In addition to making recommendations about speed and force limits in order to reduce risks when working in hazardous areas of a machine while it is in operation, the literature also proposes complementary safeguards or protective measures associated with reduced speeds and forces.

4. Excerpts from standard NF EN 415-10: 2014, *Safety of packaging machines. Part 10. General requirements*, are reproduced here with the permission of AFNOR. Only the full original text of the standard, as distributed by AFNOR Éditions—available online from www.boutique.afnor.org—has the authority of a standard.

The complementary protective measures most frequently discussed in the literature are listed below:

- Hold-to-run control
- Nearby emergency stop
- Automatic opening device (or reversal of movement device)
- Safe clearance
- Enabling device
- Minimum distance between a fixed component (e.g., built) and a movable component
- Sound signal
- Operating mode selector switch
- Training
- Placement of control device so that hazard zone can always be seen by person operating control device

There are a variety of protective measures associated with reduced-speed/force mode and their effectiveness varies. Manual or hold-to-run controls are the most common safeguards. They are generally recommended for machine start-up, as they allow workers to retain control over hazardous parts at all times while they are in hazard zones. In addition, in all cases, and especially when several workers are present in the hazard zone simultaneously, it is recommended that the control device be placed so that the associated hazard zones can always be seen by the person controlling machine movement [10]. The worker at the controls can then easily communicate with his or her colleagues, but also stop machine movements immediately if a problem arises, which should cause the machine to shut down. The use of a hold-to-run control is one of the requirements of section 186 of the Quebec ROHS.

Similarly, some standards contain recommendations about the level of reliability of the control system for secondary devices, such as hold-to-run controls. For instance, standard ANSI B65.1:2011 [32] includes the following indications regarding hold-to-run controls:

> *Guard circuitry for the hold-to-run condition shall satisfy the requirements of PLr d of ISO 13849-1 or SIL 2 of IEC 62061.*

The recommendations proposed in the literature on the level of reliability of control systems are listed in Table 8.

Table 8 – Recommendations on reliability of control systems for reduced-energy operating modes.

STANDARD	RECOMMENDATIONS ON RELIABILITY
EN 1010-5:2005	Category 1, EN 954-1:1996
ANSI B65.1:2005 and B65.2:2005	Category 3, ISO 13849-1:1999
ANSI B65.1:2011	PL_r d, ISO 13849-1:1999, or SIL 2, IEC 62061
NF EN 1010-4:2004	Category B, EN 954:1996
ISO 11111-6:2009	Category 3 or 4, ISO 13849-1:1999
NF EN 12417+A2:2009	Category 3, EN 954:1996
NF EN 1034-5+A1:2010	Category 1, EN 954:1996

Note that the categories of EN 954-1:1996 [54] are the same as those of ISO 13849-1:1999 [55].

4.2 Results of Company Visits

The second objective of the study was to visit different types of companies in order to

- Understand and characterize the situations in which work is done in reduced-energy mode
- Measure and record, if possible, the reduced-energy levels used
- Understand the choices made and identify the benchmarks used by companies
- Determine the factors that influence the levels chosen, i.e., the reasons why these levels are used

The workplace visits allowed us to see how section 186 was being applied in real situations. A total of nine visits were made, during which 15 machines were observed in different industries, as shown in table 9 and table 10. table 9 gives an overview of the visits, specifying the types of machines and the industries.

Table 9 – Machines observed on company visits and their industry.

VISIT	MACHINE	INDUSTRY
A	1 horizontal machining centre	Manufacturing
B	1 winder	Pulp and paper
C	1 printing press	Printing
D	1 printing press, 2 cardboard processing machines (extruders), 1 paper recovery machine (unwinder/rewinder)	Agri-food
E	1 printing press	Printing
F	3 six-axis robots (2 pallet loaders, 1 bagger) and 1 parallel robot (sorter)	Horticulture and agri-food
G	1 six-axis robot	Agri-food
H	1 six-axis robot	Agri-food
I	1 printing press	Printing

Table 10 presents the main working conditions observed on company visits. When it was impossible to directly observe work in reduced-speed/force mode, the information was taken from answers to questions put to workers, who demonstrated the various controls used. This was more a case of simulation than observation. The columns of table 10 describe (i) the machines concerned, (ii) the hazards in the work area against which protection was needed, (iii) the control used, (iv) the disabling or not of a guard or safety device, (v) speed values, (vi) complementary protective measures and (vii) whether reduced-speed/force mode was part of the manufacturer's original installation or whether the company installed it later.

Table 10 – Work conditions observed on company visits.

MACHINE	HAZARDS	CONTROLS USED	DISABLE?	SPEEDS	COMPLEMENTARY SAFEGUARDS	ORIGINAL MODE?
Horizontal machining centre	Entrapment, crushing, shearing	Remote control (wired) with wheel (notch = step; continuous turning = continuous advance)	Yes	V_X = 27 mm/s (1.63 m/min) V_Y = 86 mm/s (5.15 m/min) V_Z = 70 mm/s (4.17 m/min)	- Emergency stop on remote control - Advance by inching/jogging	Yes
Winder	Blades Nip points Rotation of parent roll (hazard in case paper tears at high speed)	Control panel (continuous advance)	Yes	V1 = 333 mm/s (20 m/min) V2 = 2,533 mm/s (152 m/min) Depending on operation	- Nip point guards serving as guides for web of paper - Fixed guards and interlocking gates with guard locking[5] added at front and rear	Yes for V1, No for V2
Printing press	Nip points Entrapment zone	Pedal (rotation) Local control panel (translation)	No	Rotation = 33 mm/s (2 m/min) Translation = 47 mm/s (2.8 m/min)	- Nip point guard - Emergency stop (inaccessible from HZ) - Hold-to-run control	Yes

5. This term is used within the meaning of standard ISO 12100:2010 [6] throughout the document, that is, guard associated with an interlocking device and a guard locking device so that, together with the machine's control system, the following functions are performed:
- the hazardous machine functions "covered" by the guard cannot operate until the guard is closed and locked;
- the guard remains closed and locked until the risk due to the hazardous machine functions "covered" by the guard has disappeared;
- when the guard is closed and locked, the hazardous machine functions "covered" by the guard can operate. The closure and locking of the guard do not by themselves start the hazardous machine functions.

MACHINE	HAZARDS	CONTROLS USED	DISABLE?	SPEEDS	COMPLEMENTARY SAFEGUARDS	ORIGINAL MODE?
Printing press	Nip points Entrapment (rollers)	Control panel (continuous advance)	Yes	167 mm/s (10 m/min) Or production speed Depending on operation	- Emergency stops - Movable interlocking guards with guard locking - Fixed nip point guards - Dead-man switch (wireless controller) - Warning sounds	No
Extruder	Nip points	Control panel (continuous advance)	Yes	167 mm/s (10 m/min) 1,667 mm/s (100 m/min) Depending on operation	- Emergency stops - Movable interlocking guards with guard locking - Fixed nip point guards - Dead-man switch (wireless controller)	No
Extruder	Nip points	Control panel (continuous advance)	Yes	2,500 mm/s (150 m/min) (cleaning) 133 mm/s (8 m/min) (crushing hazard because of roller and unguarded nip points)	- Emergency stop buttons and cables - Some nip point guards - Movable interlocking guards with guard locking	No
Unwinder/ rewinder	Nip points Entrapment (tilt table)	Control panel (continuous advance)	Yes	133 mm/s (8 m/min)	- Emergency stop - Movable interlocking guard with guard locking - Surface-scanning sensor	No
Printing press	Nip points	Local control panel (hold-to-run) Remote control (in tunnel, hold-to-run)	Yes	83 mm/s (5 m/min)	- Nip point guard - Emergency stop - All other controls are disabled	Yes
6-axis robot	Movement of arm–Impact Entrapment	Wired remote control (hold-to-run and enabling button)	Yes	max 250 mm/s (15 m/min)	- Emergency stop - Key transfer system (conveyors stopped)	Yes

MACHINE	HAZARDS	CONTROLS USED	DISABLE?	SPEEDS	COMPLEMENTARY SAFEGUARDS	ORIGINAL MODE?
6-axis robot	Movement of arm–Impact Entrapment	Wired remote control (hold-to-run and enabling button)	Yes	max 250 mm/s (15 m/min)	- Emergency stop - Key transfer system (conveyors stopped)	Yes
6-axis robot	Movement of arm–Impact Entrapment	Wired remote control (hold-to-run and enabling button)	Yes	max 250 mm/s (15 m/min)	- Emergency stop - Light curtain	Yes
Parallel robot	Movement of arm–Impact Entrapment	Wired remote control (hold-to-run and enabling button)	Yes	max 250 mm/s (15 m/min)	- Interlocking guard - Emergency stop	Yes
6-axis robot	Movement of arm–Impact Entrapment	Wired remote control (hold-to-run and enabling button)	Yes	max 250 mm/s (15 m/min)	- Interlocking guard with guard locking - Emergency stop	Yes
6-axis robot	Movement of arm–Impact Entrapment	Wired remote control (hold-to-run and enabling button)	Yes	max 250 mm/s (15 m/min)	- Interlocking guards (2 for the enclosure)	Yes
Printing press	Nip points	Control panel (continuous advance)	No	Phasing speed = 38 to 76 mm/s (2.27 to 4.55 m/min) Slow speed = 167 mm/s (10 to 20 m/min) Depending on format of paper	- Emergency stop	Yes

4.2.1 Characterization of Work Observed Requiring Reduced-Speed/Force Mode

During the company visits, the main types of work requiring the operation of accessible hazardous parts were documented. The relevant data gathered are presented in Table 11.

The columns of the table provide the following information: (i) the machine in question, (ii) the nature of the work, (iii) the approximate time the work took, (iv) an indication of whether the work was done in reduced-speed mode or production mode, and (v) the information provided by companies to explain their choices or situation.

In four instances, work was done at production (not reduced) speed. This work falls into two categories: the first concerns tasks that could be performed when the machine is stopped, but are not, for time and lost-paper production reasons. The second category concerns adjustments that it is deemed cannot be made adequately at lower speeds. Most tasks requiring the operation of hazardous parts are done at reduced speeds.

Table 11 – Work observed requiring reduced-speed/force mode

MACHINE	WORK	APPROXIMATE TIME	REDUCED SPEED (RS) OR PRODUCTION SPEED (PS)	REASON GIVEN FOR OPERATION OF HAZARDOUS PARTS
Horizontal machining centre	Monitoring of points of reference	1 h	RS	Need to place tools at precise positions for taking measurements, while monitoring and reading measurements on tools
	Working clearance	30 min–12 h	RS	
	Measurements (installation and calibration of measuring equipment)	30 min–3 h	RS	
Winder	Threading of paper	10 min	RS	If the rollers aren't turning, it is impossible to thread the web of paper through
	Quality control of paper	2 min	RS	Transparency control of a certain length of the paper web
Extruder	Manual threading of paper	30 min	RS	If the rollers aren't turning, it is impossible to thread the web of paper through
	Unblock blades, replace spigot	3–4 min	PS	So as not to waste too much time on a very short operation
	Adjustment of finish	5 min	RS or PS	So that the finish doesn't stick
	Various adjustments	2 to 4 min	PS	The adjustments will not be satisfactory if made at a speed other than production speed
	Cleaning rollers	15 min	RS	To gain access to the entire roller surface
Unwinder/rewinder	Manual threading of paper	10 min	RS	If the rollers aren't turning, it is impossible to thread the web of paper through
	Defect detection	30–45 min	RS	Need to monitor the paper web while it is being unwound to detect defects in the paper
Printing press	Manual threading of paper	30 min–1 h	RS	If the rollers aren't turning, it is impossible to thread the web of paper through
	Cleaning rollers	15 min	RS	To gain access to the entire roller surface
	Cleaning rollers	A few seconds	PS	So as not to waste too much time on a very short operation
	Format-related	1–2 min	RS	To check adjustments

MACHINE	WORK	APPROXIMATE TIME	REDUCED SPEED (RS) OR PRODUCTION SPEED (PS)	REASON GIVEN FOR OPERATION OF HAZARDOUS PARTS
	adjustments			
	Maintenance of distributing rollers	Up to 2 h	RS	To check thickness and distribution of ink between two rollers
	Unjamming	30 min–1 h 30 min	RS	Movement required to unjam
	Change blanket	30 min	RS	To wrap blanket around roller
	Adjust “magic eye”	Up to a few hours	RS	Check cameras that “read” the moving paper

4.2.2 Hazard Zone Access and Complementary Safeguarding

Section 186 prescribes the solutions to be applied in cases where workers must enter the hazard zone of a machine while it is running. Observations revealed that these prescriptions are not always followed in compliance with the regulation.

4.2.2.1 Hazard Zone Access and Disabling of Safeguards

One of the key points of the application of section 186 is access to a machine's danger (hazard) zones. A zone is described as being dangerous (hazardous) if hazardous parts are accessible. Section 186 specifies that to enter these zones, a worker must *move or remove a protector, or neutralize a protective device*. table 12 presents the means used to enter the various hazard zones observed on company visits.

Table 12 – Means of access used when work observed or simulated.

	MEANS OF ACCESS	NUMBER/ TOTAL NUMBER OF MEANS OF ACCESS
A	Work close to hazard, without removing fixed or movable guards	2/17
B	Open a guard that has no protective device	1/17
C	Open an interlocking guard	3/17
D	Open an interlocking guard with guard locking	6/17
E	Open a guard that has a key transfer system	2/17
F	Disable an optoelectronic device	2/17
G	Remove hazardous parts from machine (see figure 4)	1/17

For some machines, like printing presses, there are several ways to gain access to various hazard zones. For these machines, most points of access are restricted by movable guards, but at the ends, where paper reels must be moved in and out, a light curtain is often a more convenient means of covering a substantial distance. In one case (B), the interlocking device of a movable guard was removed for reasons unrelated to the reduced-speed operating mode. This change had a direct impact on the safety of the workers who used this means of access by making the hazard zone accessible.

Furthermore, of the 17 means of access surveyed, 13 involved disabling a protective device. The term "neutralization" (disabling) is used with reference to protective devices, one of the main functions of which is to prevent hazardous parts from moving when they are activated. In the case at hand, this was "controlled" disabling of a device, in contrast with disabling a protective device by purely and simply cancelling its effect, without any other measure being taken. Here, the protective devices authorized the operation of hazardous parts not only when a specific operating mode was selected (in compliance with section 186), but also on condition that speeds did not exceed an upper limit deemed safe.

For changing the plate and cleaning the blanket, one of the presses observed offered a special choice. The two rollers concerned were on a “cassette” that could be taken out of and put back into the printing unit (figure 4). The parts that constituted the hazard were thus removed from the machine and formed a new hazard zone, but one where the workers had more control over the environment.

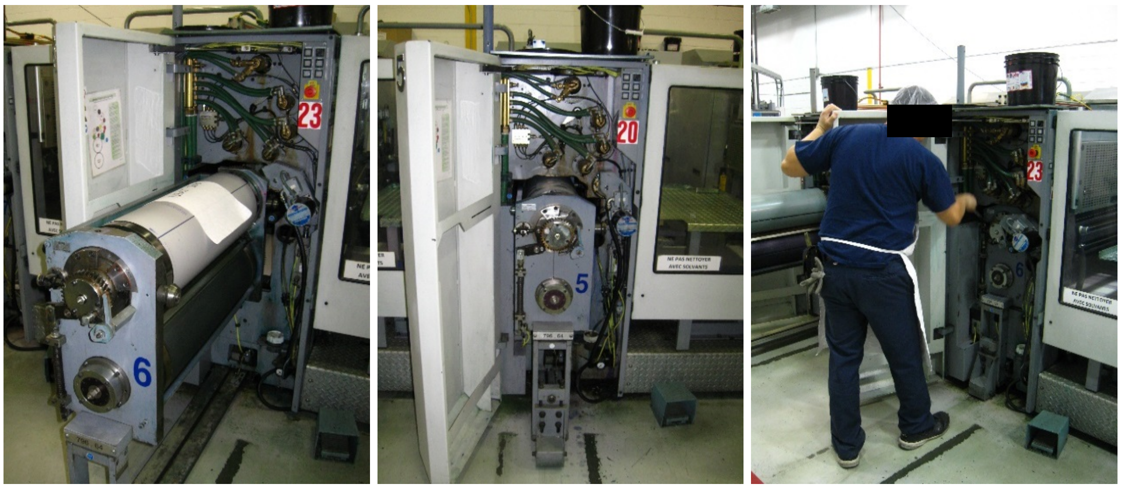


Figure 4 – From left to right: cassette removed, partly reinserted and fully reinserted in the printing unit.

4.2.3 Modes and Types of Controls Used

4.2.3.1 Continuous Running of Hazardous Parts

Table 10, in section 4.2, indicates the type of control used for reduced-speed mode. Continuous advance is one of the means observed on printing and cardboard processing machines, as well as on winders. The main hazards on these machines are the nip points. However, for the winder, the identified hazard was a whipping action if the paper broke at high speed. This hazard is virtually non-existent at reduced speeds, so speed reduction would appear to be a sufficient safeguard, even in continuous advance mode.

With respect to the hazard of being drawn into a nip point, a reduction in speed increases the chances of avoiding an accident, although without reducing the possible harm. In these conditions, the concept of controlling the movement of hazardous parts becomes more important as a factor in increasing the chances of accident avoidance. In one of the plants visited, work was performed while the hazardous parts were operating in continuous advance mode, either at production speed or reduced speed. At high-speed, workers had to keep holding down an enabling button on a remote control. If they let go, it caused an emergency stop. However, to thread the paper, workers needed to use both hands. It was decided that it would be safe to perform the operation at a rate of 8 or 10 m/min (depending on the machine) in continuous advance mode without having to use the enabling button. A slightly higher level of risk, at a speed of 100 or 150 m/min, was deemed acceptable for large-diameter roller cleaning operations. This compromise was reached as a way of reconciling worker safety with cost considerations (time the operation takes).

Moreover, at the same plant, it is interesting to note that a risk analysis identified a hazard zone that had a higher level of risk because there were no nip point guards and there was an entrapment zone because of a roller. The access doors to this zone are therefore locked permanently (even in "threading" mode, when all the doors are usually unlocked). Access to the zone is allowed only at speeds below 8 m/min (133 mm/s) with an enabling button, and provided the roller's compressed-air circuit has been disabled.

4.2.3.2 Hold-to-Run Controls

Hold-to-run controls are always used in manual mode. This mode, in contrast with automatic or semi-automatic mode, means that every movement of the machine must intentionally be initiated by workers using their hands or feet. The choice of a hand-operated control or a pedal is usually up to the designer and depends on what the worker needs to perform the operation.

For instance, when a plate must be changed on a printing press, shown in figure 5, the workers use a pedal because they have to hold the plate with both hands.

To perform the same operation on a printing press, two workers are needed. The control can be hand-operated because four hands aren't needed to hold the plate. Note that, though there doesn't seem to be an explanation for the difference, in the first case, the manufacturer opted for a speed of approximately 2 m/min (33 mm/s), while in the second case, the speed chosen by the manufacturer (different from the first one) is approximately 5 m/min (83 mm/s). These are tangential speeds measured with a tachometer near the rollers. The two situations are fairly different, one from the other, but both are considered to be safe.

The handle on the horizontal machining centre remote control (figure 6) is equivalent to a hold-to-run control. The increments are too small to allow advancing by inching/jogging, the result being that movement occurs so long as the operator continues to turn the handle. The remote controls other than those for robots were not equipped with enabling mechanisms.

Figure 5 – Using a pedal to change plates

Figure 6 – Remote control with handle

4.2.3.3 Control Priority

In addition, another important point regarding the control mode used for reduced speeds concerns control priority. This refers to the fact that selecting a specific control mode, such as remote control, must automatically disable all the other controls or at least render them inoperative for the hazard zone in question. This was the case for each of the hold-to-run controls observed (remote control and local control panel). However, the concept of priority described in section 186 assumes that the control selection mode is controllable and controlled by the operator. This means that operators must make sure that no one else can change controls or mode of operation without their knowledge. The robots observed were equipped with a key-operated selection switch for choosing between automatic mode and mode “250 mm/s – T1” (figure 7).

The operator is then supposed to keep the key so that he or she alone is able to put the system back into automatic mode once the work is finished. However, that was not the case in any of the situations observed, even if the possibility existed. It is up to the employer to establish safety procedures and ensure they are followed.

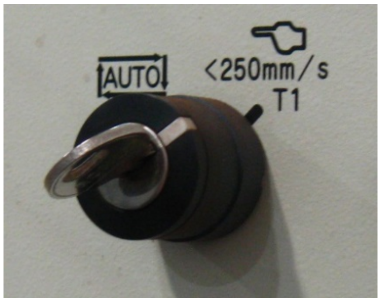


Figure 7 – Key-operated selector switch for a robot.

Key transfer systems are used in similar situations to those that require an interlocking mechanism, but they allow workers to ensure that no other person will be able to close the guard and change the mode of operation of the machine without their knowledge. However, as for key-operated selector switches for robots, it is up to operators to make sure they keep the key with them (or in a locked box if several workers are involved).

In another case observed, the remote control could be enabled simply by pushing a button ("*manche*" [joystick] button on figure 8). There was no way of locking the control setting, so anyone could select another control. Even if the cable of the remote control is pulled when someone uses it, that is not sufficient to ensure that no one enables another control. A distracted worker could simply not notice it, for instance.

Figure 8 – Remote control selection button ("*manche*" [joystick])

On a printing press that uses cassettes, when the cassettes are taken out, the rollers are physically separated from the rest of the press, and rotation is only controlled locally with the pedal. The movement of inserting and removing the cassette can, however, be initiated from the main control panel. In this regard, movement control is based on work organization and following established procedures.

4.2.4 Additional Means of Risk Reduction

The chief purpose of movable guards equipped with a protective device or a key transfer system is to prevent any start-up when the guards are open. But they are then an obstacle to the performance of tasks requiring the operation of hazardous parts. Designers, in the broad sense of the term (including integrators and user companies that may make changes to their equipment) therefore need to anticipate such situations by taking these specific tasks into account. It is then a question of allowing guards and protective devices to be bypassed while ensuring a certain level of safety. That can be done by providing for a specific mode of operation, which can be selected under defined conditions, and can be locked. Then, complementary safeguards designed to increase safety can be added.

Table 13 lists complementary means of risk reduction, identified on company visits. These means are often used simultaneously depending on the hazard and the needs of the task. The list is not exhaustive, as only the tasks observed on the visits (one to two per machine) were selected for inclusion In addition, other complementary measures can be taken on the same machine for tasks where needs are different.

Table 13 – Additional means of risk reduction identified on company visits.

CATEGORY	ADDITIONAL MEANS OF RISK REDUCTION	NUMBER/ NO. OF VISITS
Reduced energy	Reduced speed	15/15
Guard	Fixed guard (nip point or blade)	5/15
	Movable guard (nip point)	1/15
Control	Hold-to-run control	5/15
	Enabling device	7/15
Emergency stop device nearby	Mushroom push button	13/15
	Cable	1/15

To go back to the example of the printing press with removable cassettes, when a cassette is removed, only the operator can control the rotation of the rollers, using a pedal (hold-to-run control). The cassette becomes physically separate from the rest of the machine. In addition, the operator has a large clearance and benefits from a relatively neutral working position (from an ergonomic standpoint) in relation to the same operation performed on rollers in the printing unit. Nip point guards remain fixed in position permanently (figure 9).

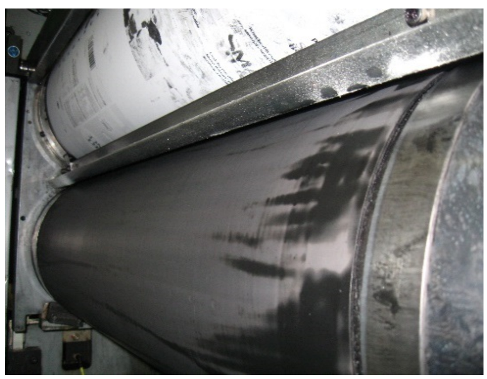


Figure 9 – Fixed nip point guard.

To control the translational movement when inserting and removing the cassette, the operator uses a hold-to-run control on a local control panel, but the same movements can be controlled from the main control panel. However, the cassettes are perfectly visible from the main panel, and the speed is reduced (≈ 3 m/min, i.e., 50 mm/s). To sum up, in this example, operators are provided with three complementary means of risk reduction: reduced speed, fixed nip point guards and a hold-to-run control (pedal).

Although already discussed earlier as a requirement under section 186, hold-to-run controls and control devices are also considered to be means of risk reduction. This is why they are listed as complementary means of risk reduction. For instance, standard ISO 1010-2:2010 [10] advocates a speed of 0.5 m/min (8 mm/s) for automatic operation, provided there is no risk of a person's trunk or head being crushed. But if this risk does exist, the standard recommends using a hold-to-run control or some other supplementary means of risk reduction.

When it was possible to perform tasks at production speed (in other words, in continuous advance mode), the complementary safeguards used consisted of an enabling device combined with a nearby emergency stop. However, in two cases, workers did not have access to an emergency stop device despite the fact the machine was operating in continuous advance mode. The machine was running at slow speed and, from the control station, the operator had a partial view (the farthest away zones being less visible) of the hazard zones where his colleague was working. The fixed nip point and blade guards eliminate or considerably reduce the risk, provided they are not removed.

4.2.5 Speed Adjustment and Selection Possibilities

ROHS section 186 has nothing to say on this topic, but whether or not machine speed can be adjusted is an important factor to take into consideration. The employer must first of all be able to maintain the safety conditions it ensures for its employees so that no one can, for instance, increase the speed above safe limits. Furthermore, when purchasing used machinery, for example, potential buyers should consider its technical specifications to determine whether they will be able to made changes if they need to. This issue was raised by one of the workers we met on a company visit, who said it isn’t always possible to make precise speed adjustments because of the characteristics of the actuators. This point is briefly discussed in the guide ED6122 published by the Institut national de recherche et de sécurité (INRS France) [56] as follows: *This principle of protecting by limiting force and energy to non-hazardous levels can be used only in cases where the characteristics of the actuator are sufficient to serve the required function (thrust, tightening, closing, etc.).* [translation]

Table 14 summarizes the information on the possibility of adjusting the maximum speed limit for reduced-energy modes of operation. In most cases, the choices have been made by the manufacturer and cannot be changed. It is assumed that the designers based their choices on risk analysis and the recommendations made in standards.

When a machine is altered by a company, speed selection is based on experience and would seem to reflect a compromise between the most reliable safe speed and one that still allows the work to be performed within a reasonable time frame. That is why the speed of 8 m/min (133 mm/s) in threading mode can be raised to 100 m/min (1,667 mm/s) to clean a relatively large-diameter roller.

Regarding the possibility of changing these speed limits, it was noted that in approximately half of the cases observed, users themselves could modify them. However, in only two cases had they been changed: in a plant where the machines had been modified and in one where a new reduced-speed mode of operation had been added. In all other cases, no need to alter the speed settings was felt.

Only one machine observed allowed anyone to change the speeds fairly simply, but the operators had never touched the adjustment controls. In the other cases, the employers knew that the operators couldn’t change anything because they would need a password or because they didn’t know how to do it.

Table 14 – Situation in companies visited concerning choice of reduced speeds.

PLANT	ORIGINAL OPERATING MODE?	WHO SELECTED SPEED?	LIMIT VALUES ADJUSTABLE?	WHO CAN ADJUST LIMIT VALUES?	RESTRICTION
A	Yes	Manufacturer	Yes	Anyone	None
B	Yes for Sp1 No for Sp2	Manufacturer for Sp1 Manufacturer's recommendation for Sp2	Yes	System engineer	Password
C	Yes	Manufacturer	Yes	Methods engineer by reprogramming the API JOG; mechanics, too, but have never changed	Password
D1	No	User	Yes, but requires in-depth knowledge	Theoretically, anyone	None
D2	No	User	Yes, but requires in-depth knowledge	Theoretically, anyone	None
D3	No	User	Yes, but requires in-depth knowledge	Theoretically, anyone	None
D4	No	User	Yes, but requires in-depth knowledge	Theoretically, anyone	None
E	Yes	Manufacturer	No	N/A	N/A
F1	Yes	Manufacturer	No	N/A	N/A
F2	Yes	Manufacturer	No	N/A	N/A
F3	Yes	Manufacturer	No	N/A	N/A
F4	Yes	Manufacturer	No	N/A	N/A
G	Yes	Manufacturer	No	N/A	N/A
H	Yes	Manufacturer	No	N/A	N/A
I	Yes	Manufacturer	No	N/A	N/A

5 DISCUSSION

5.1 Sources of Information

Guides and other research reports present simplified general rules for, for instance, implementing machine safeguarding through reduced-speed and/or force operating modes (e.g., the INRS's ED6122 [56]). When these guides or research reports deal with a precise topic, such as a specific machine, the explanations are generally clear and often well illustrated.

Still, the standards respecting machines are the primary source of information on reduced-speed and force levels. Indeed, with the exception of the three scientific papers [52], [34], [50] cited in subsection 4.1.7, all the information found in the literature outside of the standards refers directly to one or more standards. The so-called "general" standards (e.g., ISO 12100 [6], CSA Z432 [38]) that apply to machine safety regardless of the type of machine or industry make "conceptual" recommendations by presenting the reduction of speed and force (or hazardous energy) as a means of risk reduction. A few limit values are proposed, but no context is given. For example, according to Table A.2 in Annex A to standard CSA Z432 [38], the avoidance of harm is deemed likely when the speed of a component is less than 250 mm/s, regardless of the type of machine or the context in which it is used. The standard indicates this limit value in a risk matrix to determine the parameter "possibility of avoidance or of reduction in harm," which, along with other parameters (e.g., severity of harm, probability of occurrence) is used in the risk estimation process.

Standards that deal specifically with a type of machine propose values much more suited to the reality of the equipment and its use. These documents, written by industry experts or the machine manufacturers themselves, summarize risk assessment work carried out by editorial committee members. The prescriptions stated in these documents are generally easier to incorporate at the equipment design or modification stage. Some specific standards may therefore propose different values depending on the specific context of a section of the machine and the work it is anticipated will have to be performed on it.

In the case of robots, for instance, and despite the scientific recommendations mentioned above, U.S. [37], Canadian [39] and international [57] standards are unanimous in advocating a maximum reduced speed of 250 mm/s. On the other hand, for other machines, such as printing presses, several different speeds may be proposed, depending on the zone in question of a given machine. It is therefore important to know the operating basis of each piece of equipment so as to be able to correctly interpret these documents intended for machine designers and manufacturers.

5.2 Variability of Values and Determining Factors

Table 15 recaps the reduced-speed, force, energy and pressure values prescribed in the literature, regardless of industry and type of machine, as well as the values measured or observed on company visits. The small number of documents surveyed in the cases of energy and pressure explain the low number of values presented in the table for them.

Table 15 – Summary of reduced-speed, force, energy and pressure values.

Speed (mm/s), per literature	8; 10; 17; 25; 30; 33; 50; 67; 80; 83; 100; 133; 140; 152; 167; 170; 200; 250; 300; 330; 1,500
Speed (mm/s), as measured/used at company sites	27; 33; 38; 47; 70; 76; 83; 86; 133; 167; 250; 333; 1,667; 2,500; 2,533
Force (N)	20; 35; 50; 65; 70; 75; 100; 110; 125; 130; 135; 140; 145; 150; 160; 180; 200; 210; 220; 300; 500; 600
Energy (J)	3.5; 4; 10
Pressure (N/cm²)	10; 20; 25; 30; 35; 45; 50; 60; 70; 75; 80

At first glance, these values seem incompatible or contradictory, but they have to be used in very specific contexts. Taken out of context, they should only be used with extreme caution. It is very important to take into consideration everything that could conceivably have an influence on the safety that a given level of energy offers (e.g., a given speed, a given force). Without being exhaustive, the subsections below of section 5.2 present some factors that can influence the choice of reduced-energy values. The importance of conducting an in-depth risk analysis to determine the conditions under which work will be performed must not be underestimated. As part of a risk analysis, taking these factors into consideration helps in making informed decisions and in choosing appropriate means of risk reduction to achieve the desired level of risk.

5.2.1 Determining Factors

When reducing risk through energy or speed reduction, additional considerations are often taken into account. The INRS guide ED807 [43] presents several of them, which are listed in table 16.

Table 16 – Factors to be taken into account when safeguarding through energy limitation.

Factor to take into account, according to INRS	Variable concerned	Examples of parameters to consider
(1) Accessibility of hazard zone Anthropometric dimensions	Speed Force Pressure Kinetic energy	Height of hazard zone Clearance Uneven, slippery floor
(2) Pressure on parts of body	Force Pressure	Parameter to use to reduce risk Resistance to pressure depends on part of body Severity of harm depends on part of body

(3) Shape and size of contact surfaces	Speed Force Pressure Kinetic energy	Sharp, flat, rough, etc. surface Nip point, entrapment area, shearing area, etc.
(4) Kinetic energy	Speed Kinetic energy	Speed, parameter to use to reduce risk Stopping time of machine Force of impact
(5) Mechanism response time	Speed Kinetic energy	Stopping time and distance of machine

(1) The quality of the floor and the clearance are two important factors to consider that help increase the likelihood of avoidance: if the workspace does not allow a certain freedom of movement, then workers will have less chance of avoiding an accident following unintentional start-up or movement. In the INRS guide ND 2138 [27] on high-speed machining centres, the authors explain that for small machines, the speed of forward movements should be limited to 2 m/min (in manual mode, guards open and with a hold-to-run control), whereas for large machines (workspace greater than 2 m^3) the speed should be limited to 4 m/min, given the greater distances to travel and the larger clearance. Whether or not there are guards is a factor in the accessibility of the hazard zone. For instance, this approach to safeguarding was observed for a printing press at plant D3, where the speed was reduced to 2,500 mm/s for cleaning the rollers, access to which was prevented by guards. The presence of a roller and unguarded nip points elsewhere on the same machine prompted a decision to further limit the speed in this zone (to 133 mm/s).

(2 and 3) The shape of the contact surfaces also has a major impact. Contact pressure (P) is defined by the formula $P = \frac{F}{S}$. For a given force (F), the smaller the contact surface (S), the greater the resulting pressure will be. For instance, a number of standards (such as ANSI B65.1-2011 [32]) that refer to the powered closing of movable guards make the following recommendations:

- If the contact surface is a plane, the force shall not exceed 150 N.
- If the contact surface is a blunt edge, the force shall not exceed 50 N.

As a result, regardless of what part of the body is in the path of the guard, the force applied by the guard as it closes shall not exceed 50 N or 150 N, depending on the shape of the contact surface.

The review of the literature showed that force and surface pressure are used to reduce the risks related to hazards found in the following types of areas:

- Entrapment/pinching/crushing areas
- Shearing areas
- Nip points

The data in table 7, produced by the IFA, as well as anthropometric dimensions, therefore have an influence on the choice of reduced-force values.

(4 and 5) The general rule that *the slow speed chosen must allow the moving parts to come to a stop, after the control is released, in a short enough time to ensure that the operator's safety is not put at risk* [56] is a good illustration of the importance that must be given to the rotation and travel speeds of hazardous parts. The slower the travel or rotation speed, the shorter the required stopping time for a machine or its mechanisms will be. Given that the worker or workers performing this type of work will be much closer to the hazards than during normal machine operation, the speed and required stopping time are that much more important. Furthermore, the wide range of values in table 15 indicates that there is no standard reduced speed that can be regarded as safe, in whatever situation. As with the other values proposed in the literature, the reduced-speed value must be chosen based on the particular situation and therefore the different parameters listed in table 16.

(4 and 5) Kinetic energy is another important parameter to consider when examining the safety of work in reduced-speed and/or force mode. A low level of kinetic energy is used either to increase the likelihood of avoiding an accident (for example, reduction in a machine's required stopping time if a worker is drawn into a nip point) or to limit harm (e.g., reduced kinetic energy in the event of direct contact with the hazard).

5.2.2 Impact of Determining Factors

Despite the heterogeneity of the values, whether within a given field or when comparing data from all fields, an analysis of the results highlights a few general principles on the variations in recommendations related to determining factors (table 17).

Table 17 – Variations in recommendations with respect to determining factors.

DETERMINING FACTOR on reduced-energy values	State of factor allowing higher reduced-energy values	State of factor requiring lower reduced-energy values
Contact surface, geometry of moving part	Plane	Edge
Type of control	Hold-to-run control, two-handed	Pulse control (automatic movement)
Guards within hazard zone (e.g., nip point guards)	Present	Absent
Sound/light signal at start-up	Present	Absent
Accessibility of hazard zone	Hazard zone far away, hard to get to (impossible to reach)	Hazard zone close and easy to get to
Safe range of movement in case of contact	Present	Absent
Relative position of movable/fixed parts	Far apart	Close together
Automatic reversal of movement	Yes	No
Position of emergency stop device	Near hazard zone	Out of reach from hazard zone

Table 18 lists some examples of cases where the impact of the determining factors is clearly quantifiable based on the sources.

Table 18 – Series of values based on state of determining factor.

DETERMINING FACTOR	SERIES OF VALUES 1	SERIES OF VALUES 2	SOURCE
Contact surface	Plane 150 N	Edge 50 N	[32], [10]
Automatic reversal of movement	With 150 N	Without 75 N	[56], [42]
Type of control	Hold-to-run 83 mm/s	Automatic movement 8.3 mm/s	[12]

The difficulty with these determining factors is that it isn't always easy to know the limit that will determine from which series of values readers should take the information. The problem isn't about whether or not there is a hold-to-run control, or automatic reversal of movement. It is deciding from what size a surface should be considered to be too narrow an edge? What should the spacing be between the movable parts and the fixed parts of a machine for them to be considered to be at a sufficient distance from one another? Unfortunately, the reference material doesn't provide answers to these questions, leaving readers to interpret them as they see fit.

5.3 Recommendations

5.3.1 Approach to Implementation of ROHS Section 186

Implementing ROHS section 186 is an integral part of an approach to the assessment and reduction of risk in which the designer must be able to show that:

- Workers have no choice but to enter the hazard zone to perform the work and
- Performance of the work requires the operation of hazardous parts of the machine

By definition, safeguards, such as movable interlocking guards or movable interlocking guards with guard locking or protective devices (e.g., light curtain), which stop movements when they are activated and prevent any restart, are in this case ill-suited. It is therefore recommended that so-called *compensating preventive measures* [56] be taken, which allow the movement of hazardous parts once guards and protective devices have been disabled, while still ensuring a tolerable level of risk for the workers involved. This is the objective of section 186: to achieve a risk level comparable to that targeted by ROHS section 182 for work in hazard zones while hazardous parts are in operation.

These compensating preventive measures should allow factors often used to describe risk—severity of harm, hazard exposure, and possibility of avoidance—to be reduced. To reduce the factors, the focus is generally placed on

- reducing harm
- increasing the chance of avoiding harm (possibility of avoidance) and
- reducing exposure to hazards

Action can be taken on the basis of one or more of these principles.

5.3.1.1 Reducing Harm

Harm, or what can result from a hazard, can be reduced by lowering the energy level of the phenomenon regarded as hazardous. For instance, limiting the force applied to movable parts in an entrapment zone will help reduce the harm a worker may suffer. This is the elevator door principle. The kinetic energy of a moving object can be reduced by reducing its speed. Any impact will then be less forceful. Placing layers of shock-absorbing material on surfaces a person could run into will also reduce harm by dissipating the energy. Personal safety equipment (PPE) could also be worn to help reduce possible harm. For instance, some companies require protective headwear to be worn inside robot enclosures. Solutions based on the wearing of personal safety equipment should, however, be included as part of an overall procedure, in accordance with section 186.

5.3.1.2 Increasing the Chances of Avoiding Harm

When a hazardous event occurs, a worker's reaction time is one of the factors determining whether potential harm can be limited or avoided. Measures that can be taken to increase the chances of avoidance can therefore be used to reduce overall risk. For example, the purpose of a reduction in the rotation or travel speed of hazardous parts is to allow a worker more time to react to avoid getting trapped. A reduction in the force exerted can also help increase the chances of avoidance in some cases. In this regard, the INRS recommends choosing a reduced speed *so that depending on the situation, the operator has the option of stopping the hazardous movement soon enough to avoid an accident* [56]. The purpose of the prescription of section 186 to use a manual control mode (as opposed to an automatic or semi-automatic mode) is to ensure that the worker always remains in control of the movements that are generated and so is able to react by stopping the movements to avoid any harm. Standard ISO 12100 is more specific in this regard, recommending the use of a mode selector which can be locked in each position (a password on a screen could possibly be used instead of a key) [6]. The worker can then be sure that no one will be able to change the mode or, as a result, the work conditions.

Furthermore, and still with the same objective, section 186 stipulates that the hazardous parts may only be put into operation using a hold-to-run control. This control ensures that the operator who detects a potentially hazardous event can stop the movement fast enough by releasing the control (or by squeezing the control in the case of three-position controls). This considerably increases the chances of avoiding harm when compared with a continuous advance mode that requires having to reach an emergency button to stop the movement. Handle- or pedal-type enabling devices are considered to be hold-to-run controls under standard ISO 12100 and so they, too, may be used for this purpose.

Other means of increasing the chances of avoiding injury can also be used. Warning devices can alert workers that a machine is about to start up. Better lighting of the work area and less ambient noise also help workers to notice the development of unusual or hazardous conditions. Last, workers' experience and perception of risks can also help them react faster if a hazardous event occurs.

5.3.1.3 Reducing Exposure to Hazards

Reducing a worker's exposure to hazards is another way to reduce risk. The purpose of requiring the use of a two-hand control device, as prescribed in section 186, is specifically to workers from the hazard zone and thereby reduce their exposure to the hazards. This is the principle of keeping workers at a distance, and it is especially applicable to the performance of observation tasks in the process: for instance, for detecting malfunctions or testing operation following repair or maintenance work.

Similarly, the section of standard ISO 12100 that describes the requirements referred to in ROHS section 186 recommends restricting access to the hazard zone during work as much as possible [6]. Following this recommendation, controls that initiate hazardous movements should therefore be installed as far away as possible from the hazard zone. Solutions for cases in which observation work is required are proposed in INRS guide ED6129 [58]. Through the presentation of four examples, four operating modes for the purpose of process observation are described. They are summarized briefly in table 19.

Table 19 – Observation modes described in INRS guide ED 6129 [58].

	SAFETY PRINCIPLE
Observation hatch	Hatch with a protective device that is disabled once the observation mode has been selected. Allows observation from outside protective enclosure.
Shelter	The worker enters the protective enclosure while the machine is stopped and enters a safe zone from where he or she can start up the hazardous parts. The observation zone and type of protection are chosen depending on the hazard and the type observation required.
Protection by zones	In this case, the hazard zones inside the enclosure are equipped with protective devices that are enabled when the observation mode is selected.
"Mobile" emergency stop and enabling device	Case where it is not possible to stop the process in order to switch to observation mode. Worker uses an enabling device or an emergency stop. On its own, this solution is to be avoided as much as possible. It can, however, be combined with other measures.

5.3.2 *"Enhanced Security Conditions"* and Prescribed Values

Clause 3 of section 186 stipulates that the operation of these dangerous parts is only allowed under "enhanced security conditions." Although the means proposed in section 5.3.1 above seem relevant and useful to reduce risk, the issue of selecting and determining these so-called enhanced security conditions remains unresolved. How can we know whether the risk has been reduced to an acceptable level? In accordance with what criteria? As shown above, there unfortunately doesn't seem to be any recognized reduced-energy level or any absolute rule that could be followed to determine these same safe energy levels (force, speed, pressure, etc.) with certainty.

Generally speaking, when a standard prescribes levels to be abided by in a specific context, designers can use these same values, so long as the situation they are examining corresponds to the reality described in the standard. This approach, based on the experience of the authors of the standards, should lead to a reduction in risk, in keeping with the spirit of the requirements of section 186.

However, when no standard is available as a reference for a given type of equipment or when the standard does not describe a situation identical to the one for which the designer must determine an acceptable energy level, far more extensive work must be put into determining this level. While it is possible to extrapolate from requirements set out in standards to similar, though not identical situations, a designer must justify a choice by providing a detailed comparative analysis of the context in which the standard-based proposal is to be applied.

5.3.2.1 Generic Reduced-Speed Values

The results of this study's survey show that proposed reduced speeds range from 8 mm/s to 1,500 mm/s, depending on the situation. According to several standards, when a movable part is travelling at a speed in excess of 250 mm/s, it becomes difficult to prevent or limit harm. This value is also the speed recommended in most of the standards on robotics. Although it seems applicable in a number of different situations, it is important to realize that the context is what determines whether it makes sense to use it. As an illustration, the INRS gives an example of slow speed for welding robots [56]:

> To confirm a trajectory for the control in learn mode of a spot welding robot, a maximum slow speed of 250 mm/s is generally deemed acceptable if the operator is positioned more than 2 m away from the zone, while it should not exceed a few mm/s if the operator is right next to the zone. [translation]

To increase the chances of avoidance, this speed will vary greatly with the worker's distance from the moving part. The example of the hydraulic press brake, for which a slow travel speed of 10 mm/s is generally recommended, is also instructive. Given the short distance between the dies and the high risk of crushing, the travel speed must be significantly reduced in this case. Robots and hydraulic press brakes are two examples that are often used in guides and even in standards. They can therefore serve as valuable points of reference. Table 20 presents some basic characteristics of each type of machine (general case).

Table 20 – General characteristics describing most cases of robots and hydraulic press brakes.

ROBOT	HYDRAULIC PRESS BRAKE
Operator's body fairly close, clearance possible	Operator's hands in crushing zone, close to dies
Impact hazard	Crushing, severing, amputation hazard
Hold-to-run control and enabling device	Hold-to-run control (pedal)

Furthermore, it is interesting to note that out of all the cases found in the literature, only 10% prescribe speeds exceeding 250 mm/s. These are a few special cases in printing, pulp and paper, mining (roof-bolting machines) [41] and elevator doors [46].

5.3.2.2 Generic Values for Reduced Force, Reduced Kinetic Energy and Reduced Contact Pressure

As for reduced-speed values, the reduced-force values proposed in the reference material surveyed were quite varied. In cases where generic values must be used because no standard appears to deal with situations similar to the one for which the designer is seeking to determine a safe value, it seems that the values given in the guide of the International Social Security Association (ISSA) [41] can be used. These same values are referred to in the INRS guide [56], as well as in some standards reviewed, including standard ISO 14120 on movable guards [45] and standard EN 415-7:2006 on the safety of group and secondary packaging machines [59].

Two series of values are presented (table 21): (1) one for the case where there is no reversal of movement, and the other (2) where there is a device that allows reversal of movement in the event of contact or detection in less than a second [59]. A maximum force value of 75 N exerted on any part of the body is considered acceptable in the case where there is no reversal of movement, while a force of 150 N is considered acceptable if there is automatic reversal of movement following contact. Similarly, the maximum kinetic energy considered acceptable is four joules in the case where there is no reversal of movement, and 10 joules if there is automatic reversal of movement following contact. At least one document [59] proposes distinct maximum contact pressure values deemed acceptable in the two cases: 25 N/cm^2 without reversal of movement and 50 N/cm^2 with reversal of movement.

These values are valid so long as the parts in question have no sharp edges that could cause cuts or punctures. For example, standards are consistent in proposing 150 N, in the case of powered guards, without specifying whether there is reversal of movement, provided the surface is a plane [10], [32]. If the surface is too narrow, or angular, these same standards recommend that the closing force not exceed 50 N.

Table 21 – Summary table of force, kinetic energy, and pressure values.

	WITHOUT AUTOMATIC REVERSAL OF MOVEMENT	WITH AUTOMATIC REVERSAL OF MOVEMENT
Maximum force exerted on parts of body	75 N	150 N
Maximum kinetic energy of moving part	4 J	10 J
Maximum contact pressure	25 N/cm^2	50 N/cm^2

Table 5 and table 6 of subsections 4.1.4 and 4.1.5 respectively above show that very few publications refer to kinetic energy or surface pressure in connection with reduced-energy work. Yet, if these two variables were used, it would make it easier to devise more universal recommendations. For example, if the maximum surface pressure allowed for different parts of the body, given the shape and mass of the movable parts considered on the machine, were known, the reduced speed or force that would ensure an acceptable level of safety could simply be calculated on the basis of it. In that case, the value could be determined according to the part of the body exposed and the application, based, for instance, on the IFA table (see table 7, subsection 4.1.7.2) [52]. These values are still only experimental and, unfortunately, this approach will remain theoretical so long as the pressure values acceptable on the parts of the body are not known with more certainty.

5.3.2.3 Difficulties Determining Levels

Sometimes it is hard to determine with confidence whether the energy levels proposed in the literature will be suitable in a given situation and will provide a sufficient margin of safety. As mentioned above, reducing speed (mm/s) is one way to increase the chances of a worker being able to avoid harm. This approach is still very subjective, however, as reaction time will necessarily vary from one worker to another. Similarly, a reduction in force (N) is used to reduce the harm that might be done and/or increase the chances of avoiding harm. Reducing harm does not, however, depend solely on the force exerted by a moving part. It is especially important to know the shape of the part, the type of surface it has, etc., in order to determine the risk to which the worker is exposed and thereby reduce the subjective element. For example, a needle will most certainly pierce skin if a force of 75 N is applied to it. These two methods must therefore be used with caution, as reducing risk to an "acceptable" level will only be based, in these cases, on recommendations from the standards for a specific context.

In contrast, the pressure and temperature values proposed are much easier to use because they lend themselves to different contexts. Following the recommendations in the standards, a pressure value expressed in N/cm^2 or a temperature value in degrees Celsius can be used regardless of the context. The subjective element is therefore far smaller in these cases, and the certainty the values offer should be greater. It is therefore preferable to use caution when applying values taken from Type C standards drafted specifically for certain types of machinery when those values exceed the limits proposed in more generic publications, such as standard ISO 12100, and to make sure the context lends itself to the application.

6 CONCLUSION

This report concerns a study of section 186 of Quebec's Regulation respecting Occupational Health and Safety and its application. The purpose of the section, which prescribes a specific mode of operation, is to allow work to be performed within a machine's hazard zone, but only under certain conditions. The first objective of the study was to review the state of knowledge on *reduced-energy* modes of operation and on recommendations respecting best practices in this area. The second objective was to gain a better understanding of how ROHS section 186 is being implemented by observing work referred to in that section on different kinds of industrial machinery.

The study was an opportunity to survey the reduced-energy values proposed in the literature. Speed (mm/s), force (N), kinetic energy (J), contact pressure (N/cm^2) and temperature ($^{\circ}C$) values mentioned in the literature are presented with their references. Speed measurements were also taken in workplaces. Reduced-speed values depend on workers' chances of avoiding harm. Reduced-force, -energy and -pressure values depend primarily on the part of the body at risk and reversal of movement. However, production constraints and work requirements must be taken into consideration while ensuring optimum chances of avoiding harm.

The study also led to a better understanding of the implementation of section 186. Machines are not always designed with the requirements of this section in mind and may need to be adapted on site. Workers who perform tasks in the hazard zone do not always use a hold-to-run control or an inching/jogging advance mode. While most of the machine speeds observed on factory floors were equal to or lower than those recommended in the standards, this was not always the case, with some work being done at production speed.

Before deciding how to implement section 186, it should be determined whether there is no alternative to requiring a worker to enter the hazard zone and perform tasks while hazardous parts are in motion. If the literature prescribes reduced-energy values to abide by in a context similar to the situation studied, these values can be used, provided due care is taken to ensure that the two contexts are indeed similar. For want of a general rule, values should be chosen on the basis of a detailed risk analysis. Recommendations found in the literature cannot be transposed directly and must be adapted according to the context.

In any case, it is still difficult for designers to choose or confirm an appropriate reduced-energy value with certainty. Other studies will therefore be needed to help designers determine appropriate values more easily, especially with a view to quantifying the chance of avoiding harm when reducing it is not possible by design.

BIBLIOGRAPHY

[1] Commission de la santé et de la sécurité du travail (CSST). “Rapport annuel de gestion 2011,” CSST, Québec, Canada [En ligne]. Disponible: http://www.csst.qc.ca/publications/400/Documents/DC400-2032-5.pdf. [Dernière consultation: 27 juin 2014].

[2] Létourneau, D. et Potvin, F., “Accident mortel survenu le 30 avril 2013 à une travailleuse de l’entreprise “Rio Tinto Alcan” 3000, rue des Pins Ouest à Alma,” Commission de la santé et de la sécurité du travail, Québec, Canada, Rapport d’enquête RAP0957995, 2014. [En ligne] Disponible: http://www.centredoc.csst.qc.ca/pdf/ed004006.pdf. [Dernière consultation: 27 juin 2014].

[3] EPICEA, “Numéro de dossier 17737,” *INRS – Base de données EPICEA*. [En ligne]. Disponible: http://www.inrs.fr/accueil/produits/bdd/epicea.html. [Dernière consultation: 27 juin 2014].

[4] Publications du Québec. “Règlement sur la santé et la sécurité du travail,” *Règlement sur la santé et la sécurité du travail*. [En ligne]. Disponible: http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=3&file=/S_2_1/S2_1R13.HTM [Dernière consultation: 25 juin 2014].

[5] Association française de normalisation (AFNOR), “Sécurité des machines: notions fondamentales, principes généraux de conception. Partie 2, principes et spécifications techniques,” *AFNOR*, NF EN 292-2/A1, 1995.

[6] Organisation internationale de normalisation (ISO). “Sécurité des machines – Principes généraux de conception – Appréciation du risque et réduction du risque,” *ISO*, ISO 12100, 2010.

[7] Le parlement européen et le conseil de l’Union Européenne, “Directive 2006/42/CE du parlement européen et du conseil du 17 mai 2006 relative aux machines et modifiant la directive 95/16/CE (refonte),” Journal officiel de l’Union Européenne, 2006. [En ligne]. Disponible: http://eur lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:157:0024:0086:fr:PDF. [Dernière consultation: 27 juin 2014].

[8] Organisation internationale de normalisation (ISO), “Sécurité des machines: appréciation du risque. Partie 2, lignes directrices pratiques et exemples de méthodes ,” *ISO*, ISO/TR 14121-2, 2007.

[9] American National Standards Institute (ANSI), “American national standard: graphic technology - safety standard - printing press systems,” *ANSI*, ANSI B65.1, 2005.

[10] Association française de normalisation (AFNOR), “Sécurité des machines: prescriptions de sécurité pour la conception et la construction de machines d’impression et de transformation du papier. Partie 2, machines d’impression et de vernissage y compris les machines et les équipements de pré-presse,” *AFNOR*, NF EN 1010-2, 2010.

[11] Association française de normalisation (AFNOR), “Sécurité des machines: prescriptions de sécurité pour la conception et la construction de machines d’impression et de transformation du papier. Partie 4, machines à relier les livres, machines de transformation et de finitions du papier ,” AFNOR, NF EN 1010-4, 2010.

[12] Association française de normalisation (AFNOR), “Sécurité des machines: prescriptions de sécurité pour la conception et la construction des machines d’impression et de transformation du papier - Partie 5: machines de fabrication du carton ondulé et machines de transformation du carton plat et du carton ondulé,” *AFNOR*, NF EN 1010-5, 2005.

[13] American National Standards Institute, “American national standard: graphic technology: safety requirements for binding and finishing systems and equipment,” *ANSI*, ANSI B65.2, 2005.

[14] Association sectorielle paritaire pour la santé et la sécurité du travail du secteur de la fabrication de produits en métal, de la fabrication de produits électriques et des industries de l’habillement (ASPHME), “Grille d’autodiagnostic en santé et en sécurité du travail – Presses plieuses,” ASPHME, Québec, Canada. [En ligne]. Disponible: http://www.asphme.org/upload/pdf/GADplieuses.pdf. [Dernière consultation: 27 juin 2014].

[15] Canadian Standard Organisation (CSA), “Code régissant l’opération des presses: exigences concernant la santé, la sécurité et la protection,” *CSA*, CSA Z142, 2010.

[16] Burlet-Vienney, D., Jocelyn, S., Daigle, R., Massé, S., “Sécurisation des presses plieuses hydrauliques,” Institut de recherche Robert Sauvé en santé et en sécurité du travail, Québec, Canada, Guide RF-634, 2010. [En ligne]. Disponible: http://www.irsst.qc.ca/media/documents/PubIRSST/RF-634.pdf. [Dernière consultation: 27 juin 2014].

[17] Bello, J.-P., Cazin, B., Caillet, J.-P., Hue, G., “Travailler en sécurité sur les presses plieuses hydrauliques,” Institut national de recherche et de sécurité, France, Guide ED-879, 2011. [En ligne]. Disponible: http://www.inrs.fr/accueil/produits/mediatheque/doc/publications.html?refINRS=ED%20879. [Dernière consultation: 27 juin 2014].

[18] Gillot, J., Baudoin, J., Bello, J.-P., Blaise, J.-C., “Presses plieuses hydrauliques pour le travail à froid des métaux – Amélioration de la sécurité sur les machines – Spécifications techniques à l’usage des utilisateurs, des préventeurs et des rénovateurs,” Institut national de recherche et de sécurité, France, Guide ED-927, 2010. [En ligne]. Disponible: http://www.inrs.fr/accueil/produits/mediatheque/doc/publications.html?refINRS=ED%20927. [Dernière consultation: 27 juin 2014].

[19] Organisation internationale de normalisation (ISO), “Matériel pour l’industrie textile: exigences de sécurité. Partie 6, machines de production d’étoffes,” *ISO*, ISO 11111-6, 2009.

[20] Organisation internationale de normalisation (ISO), “Sécurité des machines: systèmes de fabrication intégrés: prescriptions fondamentales,” *ISO*, ISO 11161, 2007.

[21] Association française de normalisation (AFNOR), “Machines pour les matières plastiques et le caoutchouc: machines de moulage par injection: prescriptions de sécurité,” *AFNOR*, NF EN 201, 2009.

[22] Association française de normalisation (AFNOR), “Sécurité des machines – Prescriptions de sécurité pour la conception et la construction de machines d’impression et de transformation du papier – Partie 1: Prescriptions communes,” *AFNOR*, NF EN 1010-1+A1, 2011.

[23] Beauchamp, Y., Jaraiedi, M., Etherton, J., “Le contrôle en manuel des robots industriels: vitesse lente,” *Comptes rendus du 20ème congrès annuel de l’association canadienne d’ergonomie*, vol. 20, pp. 31-34, 1987.

[24] Association française de normalisation (AFNOR), “Sécurité des machines: prescriptions de sécurité pour la conception et la construction de machines de fabrication et de finition du papier. Partie 3, visiteuses et bobineuses,” *AFNOR*, NF EN 1034-3, 2012.

[25] American Society of Safety Engineers (ASSE), “Control of hazardous energy lockout/tagout and alternative methods,” ASSE, ASSE/ANSI Z244.1, 2008.

[26] Organisation internationale de normalisation (ISO), “Matériel pour l’industrie textile: exigences de sécurité. Partie 1, exigences communes,” *ISO*, ISO 11111-1, 2009.

[27] Lupin, H., “Centres d’usinage à grande vitesse (Centres UGV),” Institut national de recherche et de sécurité, France, Guide ND-2138, 2003. [En ligne]. Disponible: http://www.inrs.fr/accueil/produits/mediatheque/doc/publications.html?refINRS=ND%202138. [Dernière consultation: 27 juin 2014].

[28] Association française de normalisation (AFNOR), ” Machines-outils: Sécurité: Centres d’usinage,” *AFNOR*, NF EN 12417+A2, 2009.

[29] American National Standards Institute (ANSI), “Graphic technology: safety requirements for graphic technology equipment and systems. Part 3, binding and finishing equipment and systems,” *ANSI*, ANSI B65-3, 2011.

[30] Association française de normalisation (AFNOR), ““Sécurité des machines: prescriptions de sécurité pour la conception et la construction de machines d’impression et de transformation du papier. Partie 3, coupeuses et massicots,” *AFRNOR*, NF EN 1010-3, 2010.

[31] Association française de normalisation (AFNOR), “Sécurité des machines: prescriptions de sécurité pour la conception et la construction de machines de fabrication et de finition du papier. Partie 5, coupeuses,” *AFNOR*, NF EN 1034-5+A1, 2010.

[32] American National Standards Institute (ANSI), “American national standard: graphic technology: safety requirements for graphic technology equipment and systems. Part 1, general requirements ,” *ANSI*, ANSI B65.1, 2011.

[33] Organisation internationale de normalisation (ISO), “Matériel pour l’industrie textile: Exigences de sécurité. Partie 2, machines de préparation de filature et machines de filature,” *ISO*, ISO 11111-2, 2009.

[34] Beauchamp, Y., Stobbe, T.J., Ghosh, K., Imbeau, D., “Determination of a Safe Slow Robot Motion Speed Based on the Effect of Environmental Factors,” *Human factors*, vol. 33, no. 4, pp. 419-427, 1991.

[35] Karwowski, W., Parsaei, H., Soundararajan, A., Pongpatanasuegsa, N., “Estimation of Safe Distance from the Robot Arm as a Guide for Limiting Slow Speed of Robot Motions,” *Proceedings of the Human Factors Society 36th Annual Meeting*, vol. 2, pp. 992-996, 1992.

[36] Association française de normalisation (AFNOR), “Sécurité des machines. Prescriptions de sécurité pour la conception et la construction de machines de fabrication et de finition du papier. Partie 6, calandres,” *AFNOR*, NF EN 1034-6+A1, 2010.

[37] American National Standard Institute (ANSI), “American National Standards for industrial robots and robot systems: safety requirements,” *ANSI*, ANSI/RIA R15.06, 1999.

[38] Association canadienne de normalisation (CSA), “Protection des machines,” *CSA*, CSA Z432-04, 2009.

[39] Association canadienne de normalisation (CSA), “ Robots industriels et systèmes robotiques: exigences générales de sécurité,” *CSA*, CSA Z434-03, 2013.

[40] Association française de normalisation (AFNOR) “Sécurité des machines: prescriptions de sécurité pour la conception et la construction de machines de fabrication et de finition du papier. Partie 1, prescriptions communes,” *AFNOR*, NF EN 1034-1+A, 2010.

[41] Ambrose, D.H., Bartels, J.R., Kwitowski, A.J., Gallagher, S., Battenhouse Jr., T.R., “Computer simulations help determine safe vertical boom speeds for roof bolting in underground coal mines,” *Journal of safety research*, vol. 36, pp. 387-397, 2005.

[42] Association internationale de sécurité sociale, “Prévention des risques mécaniques, solutions pratiques,” *ISSA prevention series*, no. 2014, Genève, 1994.

[43] Lupin, H., Marsot, J., "Sécurité des machines et des équipements de travail: moyens de protection contre les risques mécaniques," *Institut national de recherche et de sécurité*, France, Guide ED-807, 2006.[6]

[44] Association canadienne de normalisation (CSA), "Code de sécurité sur les ascenseurs et monte-charge," *CSA*, CSA B44-00, 2003.

[45] Organisation internationale de normalisation (ISO), "Sécurité des machines: protecteurs: prescriptions générales pour la conception et la construction des protecteurs fixes et mobiles," *ISO*, ISO 14120, 2007.

[46] Association française de normalisation (AFNOR), "Règles de sécurité pour la construction et l'installation des ascenseurs. Partie 1, ascenseurs électriques," *AFNOR*, NF EN 81-1+A3, 2010.

[47] Lupien, T., "Action sur les machines: le massicot droit," Association sectorielle paritaire de santé et de sécurité du travail, secteur imprimerie et activités connexes, Québec, Canada, fiche technique, 2010. [En ligne]. Disponible: http://www.aspimprimerie.qc.ca/fichier/contenupublication/Action_Machine_Massicot.pdf . [Dernière consultation: 27 juin 2014].

[48] Association française de normalisation (AFNOR), "Sécurité des machines d'emballage. Partie 8, cercleuses," *AFNOR*, NF EN 415-8, 2008.

[49] Organisation internationale de normalisation (ISO), "Ergonomie des ambiances thermiques: méthodes d'évaluation de la réponse humaine au contact avec des surfaces. Partie 1, surfaces chaudes," *ISO*, ISO 13732-1, 2008.

[50] Kuivanen, R., Kwarowski, W., "Experimental study to determine safe limit for reduced speed of robot motions," *Ergonomics of Hybrid Automated Systems III. Proceedings of the Third International Conference on Human Aspects of Advanced Manufacturing and Hybrid Automation*, p 475-80, 1992.

[51] Park, J.-J., Song, J.-B., Haddadin, S., "Collision analysis and safety evaluation using a collision model for the frontal robot–human impact," *Robotica*, pp. 1-15, 2013.

[52] Institut für Auslandsbeziehungen (IFA), "BG/BGIA risk assessment recommendations according to machinery directive: design of workplaces with collaborative robots," *Deutsche Gesetzliche Unfallversicherung*, 2011.

[53] Association française de normalisation (AFNOR), "Sécurité des machines d'emballage. Partie 10, prescriptions générales," *AFNOR*, EN 415-10, 2014.

6. This publication has been replaced by INRS guide ED-6122 [56].

[54] Comité européen de normalisation (CEN), " Sécurité des machines: parties des systèmes de commande relatives à la sécurité," *CEN*, EN 954-1, 1996.

[55] Organisation internationale de normalisation (ISO), "Sécurité des machines - parties des systèmes de commande relatives à la sécurité. Partie 1, principes généraux de conception," *ISO*, ISO 13849-1, 1999.

[56] Blaise, J.-C., Lefèvre, B.-D., Lupin, H., Marsot, J., Wélitz, G., "Sécurité des équipements de travail. Prévention des risques mécaniques," Institut national de recherche et de sécurité, France, Guide ED-6122, 2012. [En ligne]. Disponible: http://www.inrs.fr/accueil/produits/mediatheque/doc/publications.html?refINRS=ED%206122. [Dernière consultation: 30 juin 2014].

[57] Organisation internationale de normalisation (ISO), " Robots et dispositifs robotiques: exigences de sécurité pour les robots industriels. Partie 1, robots," *ISO*, ISO 10218-1, 2011.

[58] Blaise, J.-C., Wélitz, G., "Sécurité des machines. Modes de fonctionnement protections neutralisées," Institut national de recherche et de sécurité, France, Guide ED-6129, 2012. [En ligne]. Disponible: http://www.inrs.fr/accueil/produits/mediatheque/doc/publications.html?refINRS=ED%206129. [Dernière consultation: 27 juin 2014].

[59] Association française de normalisation (AFNOR), "Sécurité des machines d'emballage. Partie 7, machines de groupe et d'emballage secondaire," *AFNOR*, EN 415-7, 2008.

APPENDIXES

APPENDIX A – BROCHURE PRESENTED TO COMPANIES WHEN CONTACTING THEM

Section 186 of the Quebec Regulation respecting Occupational Health and Safety

186. Adjustment, repair, unjamming, maintenance and apprenticeship: When a worker must access a machine's danger zone for adjustment, unjamming, maintenance, apprenticeship or repair purposes, including for detecting abnormal operations, and to do so, he must move or remove a protector, or neutralize a protective device, the machine shall only be restarted by means of a manual control or in compliance with a safety procedure specifically provided for allowing such access. This manual control or this procedure shall have the following characteristics:

(1) it causes any other control mode or any other procedure, as the case may be, to become inoperative;

(2) it only allows the operation of the dangerous parts of the machine by a control device requiring continuous action or a two-hand control device;

(3) it only allows the operation of these dangerous parts under enhanced security conditions, for instance, at low speed, under reduced tension, step-by-step or by separate steps.

Research team members:

Yuvin Chinniah, Eng., PhD – Lead researcher

Polytechnique Montréal

Department of Mathematics and Industrial Engineering

P. O. Box 6079, Station Centre-ville

Montreal, Quebec H3C 3A7

Telephone: 514-340-4711, ext. 2268

E-mail: yuvin.chinniah@polymtl.ca

Barthélemy Aucourt, Jr. Eng. – Research associate

Polytechnique Montréal

Telephone: 514-340-4711, ext. 4878

E-mail: barthelemy.aucourt@polymtl.ca

Réal Bourbonnière, Eng. – Machine safety consultant

Telephone: 819-769-1786

E-mail: real@realbourbonniere.com

Study of Machine Safety for Reduced-Speed or Reduced-Force Work

POLYTECHNIQUE MONTRÉAL

Project Overview and Requirements for Company Visits

WHAT IS THIS ABOUT?

Polytechnique Montréal is conducting a research project aimed at characterizing work performed on machines while workers are protected primarily by a reduction in the operating speed or force (energy) required. The study is funded by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST).

WHY DO THE STUDY?

Every year in Quebec a number of serious and fatal accidents occur when people work on machines. In some situations, one of the solutions recommended by section 186 of the Regulation respecting Occupational Health and Safety (ROHS) is to ensure that the speed or force required to operate the machine is reduced to a level that is safe for workers.

Unfortunately, reduced-speed and -force values are unknown.

One of the goals of this study is to understand and characterize the conditions of this type of work in industry.

YOUR COOPERATION IS IMPORTANT

In order to obtain a varied representation of work situations, 20 companies will be selected in four industries in which a variety of machines are used. At this stage of the study, we are counting on your cooperation, which will be pivotal for our results.

"How can we be sure that the speed or force (energy) of our machinery is reduced enough to protect our workers?"

WHAT DO WE WANT TO OBSERVE?

We want to observe work being done that requires access to the hazard zone while machines are in operation and where reducing the speed or force of machine operation is the main risk-reduction measure.

The work may, for instance, be necessary because a machine has to be adjusted or unjammed or because abnormal operation has been detected, and the tasks must be performed while the machine is running.

A typical example of this situation is when a worker must enter a robot work cell (enclosure) and, using an enabling device, allow reduced-speed operation of the robot in order to check the programming of its path.

WHAT ARE THE CRITERIA OF THE SITUATIONS WE WISH TO OBSERVE?

The hazard zone
must be delimited and normally made inaccessible by means of a (fixed or movable) guard or a protective device (light curtain, pressure-sensitive mat, etc.).

The task
is required to meet needs other than those of normal production, such as to check for defects, or make repairs or adjustments.

The machine's speed or force (energy) must be reduced so that it becomes the primary means of risk reduction, allowing the worker to perform the task safely.

WHAT ARE THE EXPECTED BENEFITS?

More will be known about reduced-speed and -force values, as well as the characteristics of the tasks for which these safety measures are required.

The results of the observations made during the visits, organized in table form, will be presented to each of the companies that take part in the project.

With these results, accident prevention officers will be better equipped to assess worker safety in connection with implementing ROHS section 186.

Ultimately, workers will benefit from improved safety.

APPENDIX B – COVERING LETTER PRESENTED TO COMPANIES WHEN CONTACTING THEM

Montreal, October 22, 2012

POLYTECHNIQUE MONTRÉAL

Yuvin Chinniah, Polytechnique Montréal

Barthélemy Aucourt, Polytechnique Montréal
Réal Bourbonnière, machine safety consultant

Research Project
"Reduced-Speed or Reduced-Force Work"

Re: Requirements for observing real work situations

Dear Sir or Madam:

Every year in Quebec a number of serious and fatal accidents occur when people are working on machines. In some situations, one of the solutions recommended by section 186 of the Regulation respecting Occupational Health and Safety (ROHS) is to reduce the machine's speed or force of operation to a level that is safe for workers.

Polytechnique Montréal is conducting a research project aimed at characterizing work performed on machines while workers are protected primarily by a reduction in the operating speed or force (energy) required, as recommended in ROHS section 186. This study is funded by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST).

Company visits are one of the major stages in the project, and that is why we are asking you for your help with identifying tasks performed and work situations occurring under conditions related to the application of section 186, during which the speed or force (energy) of operation of machinery is reduced to a level deemed safe for workers.

Situation Selection Criteria

For the purposes of the study, the tasks during which this risk reduction measure is used must have certain specific characteristics:

1. They must be performed as part of **adjusting, unjamming, maintenance, apprenticeship, repairs, a manufacturing process change, fault detection or cleaning**. Production-related tasks are excluded.

2. To perform the task, access to the hazard zone must require **withdrawing or disabling a (fixed or mobile) guard** or a protective device (light curtain, pressure-sensitive mat, etc.).

3. The machine or equipment must be **running** while the task is performed.

4. The **speed or force (in terms of energy) must be reduced** to a level deemed safe to ensure workers are adequately protected. For instance, the reduction could be applied to the rotation speed of a roller, to the travel speed of a moving component, to the temperature of a heating element, or to the maximum closing force of a robot gripper.

Examples

A chocolate candy manufacturing machine that uses a conveyor that has to be cleaned periodically would be one example. The cleaning has to be performed while the conveyor, normally made inaccessible during production by a movable guard, is still running, but at a reduced forward speed.

Another example would be the programming of a robot, where the path of the robot has to be observed in person on site. The speed of the robot’s movements would then be limited to a speed deemed safe for workers who are inside the enclosure that normally prevents access to the hazard zone.

Details of Visit Procedure

The research team is made up of three people, at least two of whom will conduct the visit. For the purposes of the visit, an operator and/or a mechanic will need to be on hand to perform the task to be observed and to answer any questions the research team may have.

It should also be noted that if the company has a unionized workforce, it would be better if employer and union representatives could also attend. While it is not compulsory, it would also be good if at least one local health and safety committee member were involved in the visit procedure.

Visits can be held anytime during the day, at your convenience. A typical visit usually takes about half a day.

Using observation checklists developed specifically for this purpose, the researchers will describe as accurately as possible the work situation they are shown. Following the visit, a copy of the completed checklist with all the recorded observations will be given to the participating company’s representative. Although the researchers will not produce an expert’s report or a consulting study, the team members will be happy to try to answer, to the best of their knowledge, any questions that visit participants might have.

Any information collected will be kept confidential, and companies generally insist on having research project officers sign letters of confidentiality.

On behalf of the research team, we wish to thank you in advance for your cooperation, which will be crucial to the success of this project.

Yours sincerely,

Yuvin Chinniah, Eng., PhD – Project lead researcher
Barthélemy Aucourt, Jr. Eng. – Research associate
Réal Bourbonnière, Eng. – Machine safety consultant

APPENDIX C – DATA COLLECTION FORM USED FOR COMPANY VISITS

DATA COLLECTION FORM

For the
research project

"Study of Machine Safety for Reduced-Speed or Reduced-Force Work"

Completed by: ______________________________

Date: ______________________________

Place: ______________________________

Hosting company: ______________________________

Machine observed: ______________________________

Instructions

To fill in this form, gather the required information by putting questions to company representatives, asking a qualified worker to perform functional testing or by observing the work environment.

Part A: Making Contact and Characterizing Tasks

This part of the questionnaire is to be completed in a meeting room. The questions concern only the machine that is going to be observed. However, any additional relevant information can be entered in the “Comments” boxes.

Part A objectives: Identify plant and representatives involved.

Identify work that needs to be done when machine running, with accessible hazards.

Characterize reasons and requirements for work.

A.1 Identification of plant and representatives

NAME OF PLANT:	
ADDRESS:	
WORKFORCE:	

REPRESENTATIVES			
First name	**Last name**	**Title/Function in plant**	**Contact information**

A.2. Do you perform work that requires the machine to be kept running, when some hazards are without guards and are accessible?

☐☐
Yes ☐No

A.3. Is it in ☐Production mode (normal speed/force)?

☐Reduced-speed/force mode?

A.4. **In what mode?** ☐Automatic ☐Semi-automatic ☐Manual

A.5. **Comments**

A.6. Characterization of work that requires machine to be kept running

For the table below, consider only the machine or part of the machine selected for the visit and put similar tasks on the same line.

Machine or part of machine being observed: _______________

Task	**Reason** for task	**Time** for task	**Frequency** of task	**Reduced (R) or production (P) S/F?**	**Why** does machine need to be kept running?
				☐R ☐P	
				☐R ☐P	
				☐R ☐P	
				☐R ☐P	

A.7. Comments

A.8. Have there been any accidents/incidents when machine running? ☐Yes ☐No

A.9. If so, please describe:

A.10. Have there been any accidents/incidents when reduced-speed/force mode was being used? ☐Yes ☐No

A.11. If so, please describe:

A.12. Comments

Part B: Study of Reduced-S/F Mode

This part of the questionnaire is to be completed in a meeting room. The questions concern only the machine covered by the visit. However, any additional relevant information can be entered in the "Comments" boxes.

Part B objectives: Identify speeds and/or force levels used by default or set on the machine.

Identify company needs (why was this mode added, situation with regard to standards and regulations).

Understand setting choices and constraints on these choices.

B.1. Reduced-speed/force mode part of original design of machine? ☐Yes ☐No

If yes, go to question B. 5.

B.2. If not, why was this operating mode added (required for task, to facilitate production, to improve safety, etc.)?

B.3. How was this operating mode added (program modification, controls added, etc.)?

B.4. Who added this operating mode?

☐Manufacturer	☐User (specify):	☐Other (specify):

B.5. In your opinion, which category or categories best describe the tasks that must be performed in reduced-speed/force mode (check all that apply)?

Note: Do not refer to the literature. Ask the question only in relation to the type of tasks (adjustment, unjamming, etc.).

ROHS sec. 186 [1]:

☐Adjustment

☐Unjamming

☐Maintenance

☐Apprenticeship

☐Repair, including detection of abnormal operations

ISO 12100-2010 [2]: ☐Manufacturing process changeover

☐Fault finding

☐Cleaning

B.6. Reduced-speed value on machine: _______________

Reduced-force value on machine: _______________

B.7. Value based on documentation? If so, record the type and reference of the document(s).

☐Standard	Indicate reference:
☐Guide	Indicate reference:
☐Scientific paper	Indicate reference:
☐Other	Indicate reference:

B.8. If not, how did you determine the value (e.g., experience, trial and error, stopping time/distance)?

B.9. Choice made by:

☐Manufacturer ☐ Adjuster/Fitter ☐Operator ☐Maintenance personnel ☐Other: _______________

B.10. Comments

B.11. Is it possible to modify the reduced-speed/force value? ☐Yes ☐No

If so, who may make the change and how**?**

____

B.12. **Access restriction:** ☐None ☐Password ☐Key ☐Other (specify): ____________

B.13. **Are there any technical (e.g., manufacturing) constraints that limit/influence the selection of the value?** ☐Yes ☐No

B.14. **If so, what constraints?**

B.15. **Comments**

Part C: Identification of machine/hazard zone studied and observation of work performed in reduced-speed/force mode

Part C objectives: Identify all existing means of risk reduction.
Observe and characterize work conditions.
Identify risks.

C.1. Note down information on machine being observed

Machine		Internal Reference No.	
Make			
Year of manufacture		Year of installation	
Model		Serial No.	
Labelling (e.g., CE, CSA)			

C.2. Identify the means of risk reduction in place on the machine observed for the work area in reduced-speed/force mode

Means of risk reduction and protective devices in place		Quantity	Observation (e.g., open/closed, activated/deactivated, moved, disabled)
1	☐Fixed guard		
2	☐Adjustable guard		
3	☐Automatic closing guard		
4	☐Movable guard without guard locking (definition according to standards, and not ROHS)		
5	☐Movable guard with guard locking (definition according to standards, and not ROHS)		
6	☐Movable guard with interlocking (definition according to standards, and not ROHS)		
7	☐Enclosure (Number of doors→)		
8	☐Fixed nip point guards		
9	☐Pressure-sensitive nip point guards		

10	☐Pressure-sensitive edges		
11	☐Pressure-sensitive mats or surface detectors		
12	☐Light curtains		
13	☐Press brake optical detector (laser)		
14	☐Other (specify, e.g., established procedure):________________		

***Disabled** = deactivated or function modified (e.g., movable guard opened to allow reduced-speed operation instead of preventing any resumption of movement after opening)

C.3. Comments

C.4. Control panels or remote controls available for machine:*

☐Wired remote control ☐Wireless remote control ☐Control panel

☐Other (specify): ________________

*Note: This concerns the machine's operating controls, and not the safety control system.

C.5. Types of emergency stop (ES):

☐Cable	Quantity:	____________			
	Taut:	☐Yes	☐No		
	Easily noticeable:	☐Yes	☐No		
	Easily accessible:	☐Yes	☐No		

☐Button	Quantity:	____________			
	☐Red	☐Not recessed	☐Mushroom type	☐On yellow background	☐With manual reset
	Easily noticeable:	☐Yes	☐No		
	Easily accessible:	☐Yes	☐No		

☐Pedal	Quantity:	____________	
	Easily noticeable:	☐Yes	☐No
	Easily accessible:	☐Yes	☐No

☐Bar	Quantity:	____________	
	Easily noticeable:	☐Yes	☐No
	Easily accessible:	☐Yes	☐No

☐Handle	Quantity:	__________________	
	Easily noticeable:	☐Yes	☐No
	Easily accessible:	☐Yes	☐No

C.6. Draw a plan showing hazard zone (geometry), guards, position of controls and emergency stop (ES)

Observe the workers and fill in the table below regarding the task observed, take photos.

C.7. Task observed: ____ **Number of workers:** _________

C.8.

Risks observed	Safeguards observed	Worker's position			State of safeguard		
		Close[1]	In path[2]	Contact[3]	Used[4]	Moved[5]	Disabled[6]
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□
		□	□	□	□	□	□

[1] Close = within arm's reach (≈ 850 mm)

[2] In path = in the path of a moving part

[3] Contact = direct or indirect (tool) contact with hazard

[4] Used = safeguard in place and used as is

[5] Moved = guard dismantled, safeguard eliminated

[6] Disabled = modified or bypassed

Examples of common hazards: nip point (cylinder/cylinder, cylinder/material, pulley/belt, disk/flat surface, etc.), moving part, moving sharp or pointed parts, temperature, moving part (size and shape of contact surface), etc.

C.9. Comments

C.10. List the tools required to perform the task

C.11. Work conditions

☐Safety footwear ☐Gloves ☐Hard hat ☐Safety glasses ☐Hearing protection ☐Mask

☐Special lighting ☐Start-up warning ☐Training ☐Other (specify): ___________________

C.12. Signals to indicate selected operating mode?

☐Control panel screen ☐Signal light ☐Sound signal ☐Other (specify): __________

C.13. Access to hazard zone

☐Movable guard open ☐Fixed guard dismantled

☐Recourse to disabling of initially installed safeguard

Safeguard disabled: ____________________ How? Why?	Safeguard disabled: ___________________ How? Why?

C.14. Comments

C.15. Hold-to-run, two-hand control devices [1]

☐Two-hand control ☐Hold-to-run control ☐Dead man’s handle ☐Dead man’s pedal

☐Other (specify): __________________

What effect does the control have?

☐Continuous operation ☐ By separate steps (inching) ☐Step by step

☐Time-limited operation Note time limit: __________________

☐Distance-limited operation Note distance limit: __________________

C.16. Control means used for reduced-S/F mode

☐ Wired ☐ Remote control ☐ Fixed general control panel ☐ Fixed local control panel

☐ Cab ☐ Other (specify): __________________

Note: Reminder of number of workers: __________________

C.17. If there are several workers, who controls the movement?

C.18. How are the workers organized to ensure each one's safety (communication)?

C.19. Indicate distance between control used and hazard (cm): __________________

C.20. Is the hazard zone relevant to the task visible from the control being used? ☐Yes ☐No

C.21. Are all the machine's accessible hazard zones visible? ☐Yes ☐No

C.22. How does the system go into reduced-speed/force mode?

☐Reduced-speed/force mode selector button

Type: ☐ Selector

☐ Key-operated selector

☐ Switch/push button

☐ Other (specify): __________________

☐ When interlocked guard is opened

☐ Simple adjustment (e.g., potentiometer, change on an interface)

☐ Other (specify): __________________

C.23. Written procedure sheet must be followed for operation? ☐ Yes ☐ No

Note: Make link with C.2.: The means of risk reduction can be a "safety procedure," under ROHS section 186.

C.24. If so, is it understood and understandable by everyone (training, literacy, language)? ☐ Yes ☐ No

C.25. Comments

C.26. Where is the procedure? ☐N/A ☐ Near the machine ☐ Other (specify): ________

C.27. Is it possible to get a copy? ☐Yes ☐No

C.28. Can a test be run to check that the selected mode is operating properly? ☐Yes ☐No

C.29. If so, describe what has to be done to run the test.

Part D: Testing

The objective of this part is to run tests to answer questions about the machine observed. If that is not possible, then rely on workers' answers and note them down.

Part D objectives: Run tests to answer questions.

Determine effects of various safeguards in place.

Measure speed, force, temperature, etc., if possible.

Examine specific aspects of certain machines (identified in the literature).

D.1. ALL MACHINES

D.1.a. Regardless of the machine observed, for each safeguard in place for the hazard zone studied, determine, THROUGH TESTING,* its effects and record the results in the table below.

Safeguard	Effects observed

*If it is impossible to run a test, ask the workers the question.

Part E: Technology Used

Part E objectives: Identify technical means used to reduce and maintain speed, force, energy at what is considered a safe level (once reduced-speed/force mode has been selected).

Identify checking mechanisms in place.

E.1. Do you know how the speed, force, kinetic energy, pressure (circle applicable) **is limited technically* (once the reduced-speed/force mode has been engaged)?**

*Examples of technical means of limiting speed or force:

By limiting power (e.g., of electric motor, hydraulic circuit)

By changing the motor (i.e., install a less powerful motor)

By making an adjustment in the machine's program

Potentiometer (manual adjustment)

E.2. To which ISO 13849 [7] category or PL, or to which IEC/EN 62061 [8] SIL, does the control circuit for limiting speed or force belong?

E.3. How is the level (speed, force, etc.) controlled or checked and maintained?

☐Control circuit (SIL control loop, PL, other?) **Satisfies requirements of what ISO 13849 category?** _______

☐Other (provide details below):

E.4. Is there a speed, force, etc. indicator? ☐Yes ☐No

E.5. Type of indicator (gauge, digital readout)?

E.6. If not, how do you know whether the correct speed, force, etc., is in effect?

E.7. Generally speaking, what kind of checks do you perform before doing your work in reduced-speed/force mode? And how do you perform them?

E.8. Comments

APPENDIX D – TYPICAL PROCEDURE FOR COMPANY VISIT

Outline for typical visit (≈ ½ day)

– In meeting room:

✓ **(15 min)** Introductions, recap of project objectives, signing of "***information and consent form***"

✓ **Part A (30 min)**

Objectives:

– Identify plant and representatives
– Identify work that needs to be done when machine running, with accessible hazards
– Characterize reasons and requirements for work

✓ **Part B (45 min): Study of reduced-speed/force mode**

Objectives:

– Identify speeds and/or force levels used by default or set on the machine
– Identify company needs (why was this mode added, situation with regard to standards and regulations)
– Understand setting choices and constraints on these choices

– In plant:

✓ **Part C (1 h): Machine/hazard zone studied and observation of work done at reduced speed/force**

Objectives:

– Identify all existing safeguards
– Observe and characterize work conditions
– Identify risks

✓ **Part D (1 h): Testing**

Objectives:

– Run tests to answer questions
– Determine effects of various safeguards in place
– Measure speed, force, temperature, etc., if possible
– Examine specific aspects of certain machines (identified in the literature)

✓ **Part E (30 min): Technology used**

Objectives:

– Identify technical means used to reduce and maintain speed, force, energy at what is considered a safe level (once reduced-speed/force mode has been selected)
– Identify checking mechanisms in place

Note: The times indicated are an estimate and may be shorter or longer depending on company availability and the equipment being observed.