

VIRTUAL ENVIRONMENT FOR SAFE DESIGN

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ABSTRACT

This paper presents an avenue of research in which INRS has recently become involved. It concerns the application of Virtual Reality techniques that use haptic interfaces (force feedback systems) to assess compatibility between safety measures and the task to be performed, prior to building a machine.

INRS has conducted a technical feasibility study on simulating the operating part of a press brake machine to investigate the technical limitations of a typical virtual environment.

This simple case has enabled us to demonstrate that it is indeed possible to simulate a machine operating part with its safety devices, through the use of real-time Man-Machine interactions via suitable force feedback interfaces. In addition to visual and auditory perception conventionally considered, a force feedback interface allows the user to interact with a virtual object by touch.

Work equipment (machinery, tools, production lines, etc.) constitutes complex technical systems. In health and safety terms, it is difficult for the system designer to consider operating modes at the limit of normal and anticipated system operation. Technical, environmental and organizational constraints, unique to the activity and the industrial site, generate work situations beyond the designer's grasp and these can cause an accident and even bodily damage, under certain conditions.

Following an introduction to accident risk prevention problem areas inherent to the transition from machine design to operation, we highlight the contribution of virtual reality in terms of a dynamic simulation tool and present, more specifically, a technical feasibility study of a press-brake.

From technical system design to work situation

The main objective pursued by the machine designer - a technical system designer, above all else - is proper operation of the system he is designing, such that it meets previously drafted general and technical specifications. Observation and evaluation methods and retro-actions allow the designer to envisage potential malfunctions and take appropriate measures at design stage.

Thus, digital simulation (cf. figure 1) based on technical system models contributes to reducing the risks of technical failure-related damage by anticipating such risks. Recently, use of anthropometrical models has facilitated consideration of accessibility constraints [1] [2].

Applying general principles governing the design of safe machinery [3], successive iterations will reduce the level of risk through development of measures involving intrinsic prevention (elimination of dangerous phenomena), protection (physical, photoelectric and symbolic barriers, etc.) and information to users.

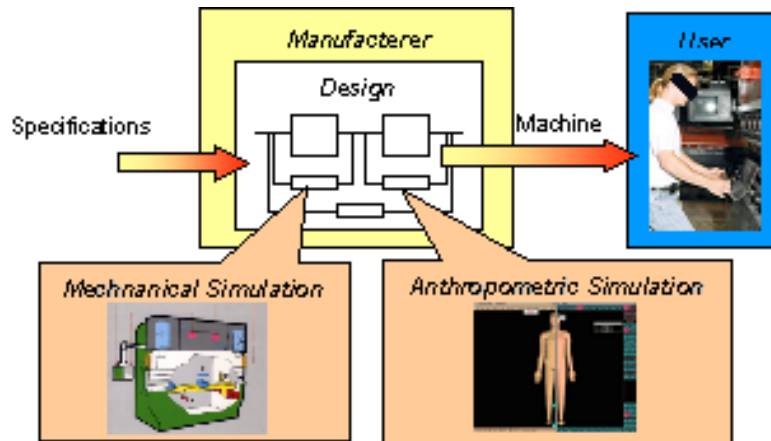


Figure 1: design and conventional simulation tools

Depending on the degree of complexity, level of distribution and specific character of a machine, a more or less clear-cut break separates a settling-up and operation phase from the foregoing design phase. A factor not originating in design is seen to enter this second phase: Man, the future user of the technical system.

The machine thus enters a new "area"; that of its usage. Whilst the designer has asked and attempted to answer the question, "How should the machine be used with respect to its designed technical characteristics?" (he will have expressed this question in terms of tasks, operating modes, directions, instructions, procedures, etc.), the user will have to ask himself, "How should I really use the machine with respect to its operating context?" ("prescription versus practice").

Many ergonomics studies have dealt with these aspects and with activity analysis methods; we refer the reader to the many references quoted in [4], a work from which we have borrowed a number of concepts in this paper.

In prevention terms and following the iterative risk reductions implemented by the designer, the user is in turn responsible for overcoming previous residual risks by adopting measures suited to the operating context (work organization, supervision, personal protection devices, training, etc.).

To achieve this, the designer must possess models representing work situations and use these by integrating them into his product design process. Research has already been conducted in this direction [5].

Moreover, the designer can test the validity of these models by applying them to situations involving real operators working in a virtual environment. This, of course, is the true challenge of virtual reality!

Virtual reality with haptic feedback as a dynamic simulation tool

Appearing at the end of the 1960s, Virtual Reality (VR) continues today to be associated with video games and certain specific sectors such as the aerospace and nuclear industries. This a restricted view of the broad possibilities offered by these new technologies. Recent advances have made possible real-time creation of synthetic images and enable one or several operators to interact with a virtual environment reproducing all or part of their work station.

In dynamic (as opposed to static) simulation, the subject does not simply reproduce a situation in a fixed environment, he influences and modifies the situation. Criticism often directed at simulated situations – their limited representativeness of real situations – will continue to disappear because technical advances are so rapid in this field. Conventionally mobilized senses such as sight and hearing have been complemented by touch, which offers the possibility of feeling movements of, and forces exerted on, the subject's body (haptic feedback) [6].

Although formerly implemented only in research laboratories, VR has now become accessible to companies and could be capable of meeting over two-thirds of simulation-related requirements in relation to human activity [7]. In the next 10 years, expected progress in the VR field permits widespread distribution of this technique to SMEs to be envisaged [8].

Occupational risk prevention-related research remains limited, but initial NIOSH¹ [9] and FIOH² [10] experiments involving handling and working at a height are worth noting. HSE³ has also studied health effects of using VR techniques [11][12].

Within the scope of research into better integration of prevention at work equipment design stage [13], INRS is currently studying how to combine the occupational risk prevention viewpoint with this major technological advance and future design tool [14]. The initial set-up in figure 1 is complemented by a retro-action loop allowing virtual environment-based simulation analyses and results to be used (cf. figure 2). Levels of residual risks originating in design should thereby be reduced.

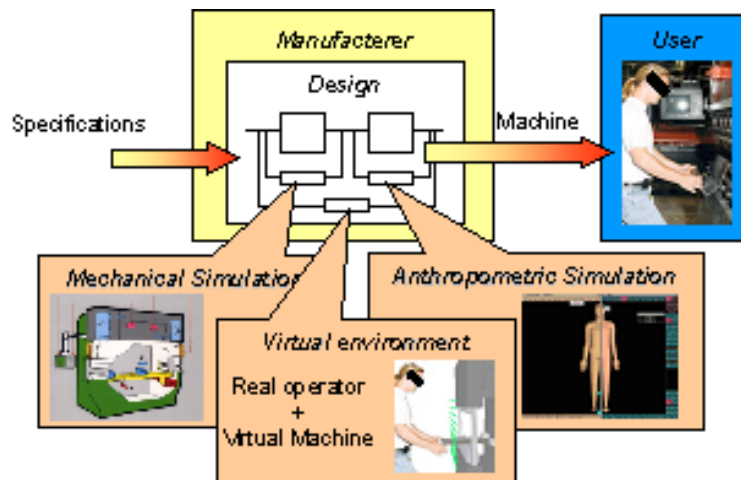


Figure 2: design and virtual environment

The research presented in this paper concerns the technical feasibility of simulating virtually a press brake with haptic interaction.

Technical feasibility specifications

The technical feasibility study involved simulating press brake operations with force feedback in a virtual environment similar to real operating conditions, by manipulating physically a real sheet-metal work piece. Various components were simulated with realistic interaction to achieve this and the following data were taken into account.

- Characteristics of the press brake operating part to be simulated, i.e. ram, bed, punch, die, back gages, work piece support, etc. (cf. figure 3).

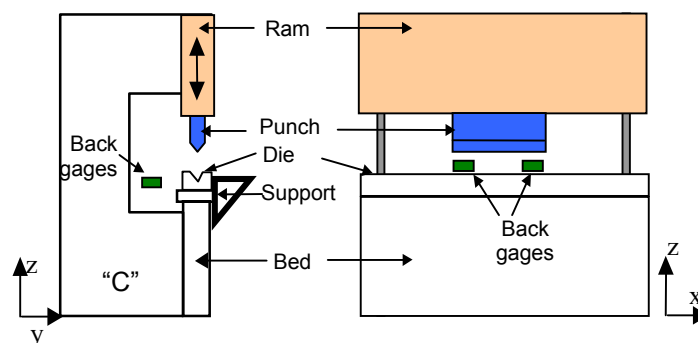


Figure 3: characteristics of operating part to be simulated

- Characteristics of safety devices to be simulated: light curtains and side guards (cf. figure 4).

¹ National Institute for Occupational Safety and Health (USA)

² Finnish Institute of Occupational Health (Finland)

³ Health and Safety Executive (UK)

- Characteristics of work piece to be folded to obtain a typical shape from a flat metal sheet (cf. figure 5).
- Simulation of grip and contact between metal sheet and all other physical simulation components as well as metal sheet movement during folding phase.
- Folding cycle scenario.

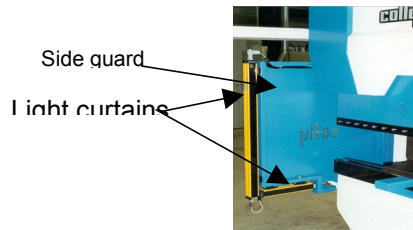


Figure 4: protection devices

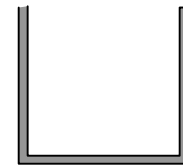


Figure 5: required folding

Description of virtual press brake simulator

Different technical components of the press brake operating part simulator comprised:

- Haptic interface: Haption Virtuose 6D-RV™ (cf. figure 6) featuring a force feedback arm, whose end fitting was fixed to a real sheet-metal plate, also held by the operator. Force feedback was therefore obtained through this sheet-metal plate via haptic interface and operator. Real metal sheet movement was displayed in the virtual scene, if the operator acted on the real metal sheet. Movement obtained, when the virtual sheet struck a virtual object, was transmitted to the real metal sheet via the Virtuose 6D-RV™ haptic interface. The solution was particularly well suited to this application, which requires a considerable amount of work space and physical effort.

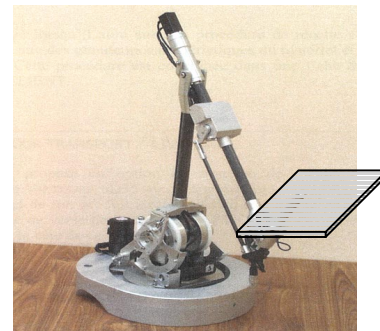


Figure 6: Virtuose 6D-RV™

- Physical real-time motor: Critical Mass Lab. Vortex™ software allowed all system components to be created: press brake, metal sheet, graphic interaction of hands and simulation of dynamic behavior, while adhering to the folding scenario. The low-level, real-time force feedback arm controller communicated with both a PC via a TCP/IP protocol, which created the virtual scene, and arm motor power amplifiers. It also controlled system stability.
- Twin screen (ground and wall) display system incorporating video projectors and stereoscopic wireless glasses.
- Display calculator, which computed images to be projected by video projectors.

An expected outcome of this feasibility study was to ascertain whether VR simulated operation of a safety device-integrated machine devices allows their integration to be improved. This is why the specification considered safety devices when modeling of press brake.

The light curtain was graphically simulated by cylindrical cut-offs representing optical beams. However, its impact model was different: it featured a box occupying the same space as the cylinders. Only the hands of the operator were inserted into the scene via trackers (cf. figure 7).

Impact between barrier model and hand models caused light beams to appear in visual alarm form (cf. figure 8).

The side guards were simply created as an impact model. The physical motor detected impacts between hands and light curtain and prevented the hands from crossing the barrier by applying contact forces.

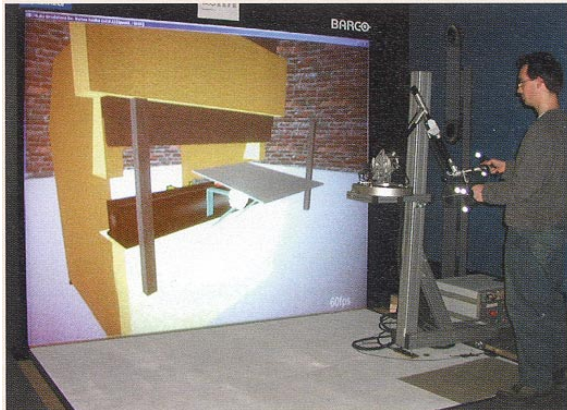


Figure 7: view of developed simulator

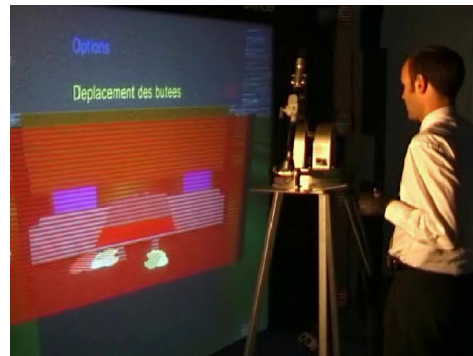


Figure 8: hand detection in danger zone
(light curtain activation)

Results and conclusion

This demonstration confirmed the technical feasibility of simulating virtually a press brake operating part with haptic interaction. The application showed that machine safety device operation can be simulated prior to development. Prototyping before production, using a virtual model, allows safety devices to be better adapted to the tasks to be performed. In information terms, VR provides an extra dimension, to the extent that it can resort to real operators capable of interacting with a fully or partially simulated system. Initial retro-action is thus made possible in the design cycle, prior to any physical development.

Furthermore, training initiatives could benefit from this virtual prototype. Knowing how to design work system usage should complement its technical design; training forms an essential prevention system component in this respect.

Limitations will of course exist and designers should use simulation results with caution. Ergonomists, the analysts of simulated activity, should rightly recall that the context is transformed in similar cases and that the operator in a simulated situation should know how to adapt his reactions and that these are necessarily different from those implemented in the real context. Despite this, a new step forward has been taken in relation to integrating prevention into work system design.

Physical “immersion” of the user in the design chain allows virtual reality techniques to provide greater understanding of future Man – System – Environment interactions and thus to more closely suit safety measures to the task to be performed. In other words, the process involves: i) at design stage, creating work situation scenarios as close as possible of anticipated operations, ii) dealing physically with virtual objects, iii) adapting operating modes and safety measures. Means will then be available to designers for using virtual machines and being able to check that procedures, instructions, etc., applied during operation, do not introduce specific risks that will reduce the system safety level. Moreover, the same virtual environment can be used to train a workforce in assembly, operational and maintenance tasks to increase their skill levels and safety awareness.

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Bibliography

- [1] INRETS “*Les modèles numériques de l’Homme pour la conception de produits*” Actes du séminaire organisé par l’Institut National de Recherche sur les Transports et leur Sécurité (INRETS), Lyon, 16 mars 2000.
- [2] NF EN ISO 14738 “*Sécurité des machines. Prescriptions anthropométriques relatives à la conception des postes de travail sur les machines.*” Paris - La Défense, AFNOR, fév. 1998.
- [3] NF EN 292 “*Sécurité des machines - Notions fondamentales. Principes généraux de conception. Partie 1: terminologie de base, méthodologie*”- Paris-La Défense, AFNOR, 33 p.
- [4] Leplat J. “*L’analyse psychologique de l’activité en ergonomie : aperçu sur son évolution ses modèles et ses méthodes* » Ed. Octarès, Coll. Travail et activité humaine, Toulouse, 2000, 164 p.
- [5] Hasan R., Bernard A., Ciccotelli J. and Martin P. “*Integrating safety into the design process: elements and concepts relative to the working situation*”. Safety Science - Special issue « Safety in design », Vol. 41 n. 2-3, March 2003, pp. 155-180, ISSN 0925-7535.
- [6] Techniques de l’Ingénieur “*L’ingénieur entre dans l’ère du virtuel*” Dossier Instantanés Techniques, mars 2001, pp. 37-45.
- [7] Fuchs F., Moreau G., Papin J. P. “*Le traité de la Réalité Virtuelle*”. Les presses de l’Ecole des Mines, Paris, 2001, ISBN 2-911762-34-7, 517 p.
- [8] I.T “*La réalité virtuelle : l’an 1 des applications industrielles*” Instantanées Techniques, Paris, 1995, pp.41-43.
- [9] Dotson B., Hsiao H., Chiou S.S., Dipasquale J.J. “*Occupational Traumatic Injury Prevention Using Virtual Reality*” National Occupational Injury Research Symposium, NOIRS Symposium, Morgantown, WV, USA, 15-17th Oct. 1997.
- [10] Laitinen H. “*Usability through Product Design: New Design Methods and Industrial Applications*” Research project, Dept. of Occupational Safety, FIOH, Vantaa, Finland, 1997.
- [11] Nichols S., Cobb S., Wilson J.R. “*Health and Safety implications of Virtual Environments: Measurement Issues*” Presence: Teleoperators and Virtual Environments. 6(6), 1997, pp. 667-675.
- [12] Cobb S., Nichols S., Ramsey A.R., Wilson J.R. “*Virtual Reality Induced Symptoms and Effects*” Presence: Teleoperators and Virtual Environments. 8(2), 1999.
- [13] Marsot J. “*Conception et Ergonomie : Méthodes, Outils et propositions d’actions pour intégrer l’Ergonomie dans le cycle de développement des Outils à Mains*” – Notes Scientifiques et Techniques de l’INRS, n° 219, Vandoeuvre-lès-Nancy, France, avril 2002, 69 p.
- [14] Ciccotelli J. “*Réalité virtuelle, une aide à la décision pour la conception de systèmes sûrs*”. In Proc. of European Conf. On System Dependability and Safety «Decision Making and Risk Management», Palais des Congrès, Lyon, 19 au 21 mars 2002.