Work 41 (2012) 5972-5976
DOI: 10.3233/WOR-2012-0996-5972
IOS Press

Ergonomic design of crane cabins: a case study from a steel plant in India

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Abstract. The study, carried out at the Batch Annealing Furnace (BAF) shop of Cold Rolling Mill (CRM) at an integrated steel plant of India, concerns ergonomic evaluation and redesign of a manually-operated Electrical Overhead Travelling (EOT) crane cabin. The crane cabin is a complex worksystem consisting of the crane operator and twelve specific machine components embedded in a closed workspace. A crane operator has to perform various activities, such as loading and unloading of coils, setting and removal of convector plates, and routine maintenance work. Initially, an operator had to work in standing posture with bent back most of the time. Ergonomically poor design of the chair and the controls, awkward work postures, and insufficient vision angle resulting in musculoskeletal disorders (MSDs) are some of the critical problems observed.. The study, conceived as an industry-academia joint initiative, was undertaken by a design team, the members of which were drawn from both the company concerned and the institute. With the project executed successfully, a number of lessons, such as how to minimize the anthropometric mismatch, how to improve the layout of the components and controls within enclosed workspace, and how to improve work posture minimizing risk of MSDs have been learned.

Keywords: complex worksystem, enclosed workspace, work posture and visibility, anthropometric mismatch, im proved specifications

1. Introduction

The study was carried out in a renowned privately owned integrated steel making company located in the eastern zone of India. The place of project work is a Batch Annealing Furnace BAF shop in a Cold Rolling Mill (CRM) plant. In BAF, the cold rolled coils are batch annealing in special vertical furnaces. These furnaces are filled with pure hydrogen for uniform heating of coils. This makes BAF a very high risk zone and causes increased psychological stress among crane operators. BAF produces about 66 % of the total production of the whole CRM. There are 24 EOT cranes presently employed in CRM plant. Out of 24 cranes, 15 are man driven, 9 are remote controlled. There are two types of man driven cranes: computer- controlled semi-automatic cranes and fully manual cranes.

The complex worksystem of BAF crane cabin consists of a human crane operator and a number of machine components. BAF is an area where all the four cranes are at elevation of 18 meters and work around the clock. There are 21 crane operators for driving BAF cranes. The crane operators have to work with this complex worksystem to perform various activities, such as loading/unloading of coils on BAF base from the coil transfer car, setting/removal of convector plates, setting/removal of inner cover, setting/removal of heating hood, setting/removal of cooling hood, setting/removal of cooling covers, supply of coils from BAF to coil car, supply of coils from coil car to Cold Coil Storage Unit (CCSU), supply of coils from CCSU to coil car, supply of

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coils from coil car to Skin Pass Mill, and random maintenance work, .complex worksystem, high elevation, varied work tasks and working in a very high risk zone is a highly demanding job, both physically and psychologically. In addition to these factors, poor design of the existing crane cabins has increased the problems for the crane operators.

2. Problems with Existing Crane Cabins

Since the commissioning of CRM plant there have been many serious problems with the crane cabins. Initially the cabins were totally unsuited to the work with operator standing and bending over the railings most of the time to look at the work zone. When the CRM was commissioned, the initial low productivity levels of just 30 % of design capacity came as a shocking realization and even getting the right equipment would deliver if the ergonomics of the system are disregarded. The remedial measures were applied and few modifications were done in the cabin, chair and control system, which at the best were haphazard, unscientific and just fire-fighting measures. These measures were able to bring the productivity levels to about 70% of design capacity. However, a number of problems, such as poor visibility, ergonomically inappropriate placement of controls, indicators and components, misfit between man and machine at various levels, extreme awkward postures held static for long periods of time, chair unsuited for task requirements of the operators and cluttered and congested cabin still persisted.

The poor ergonomic design of the BAF crane cabins resulted in many serious problems. The crane operators have to adopt awkward postures during work due to obstructed vision and high elevation of the crane. The misfit between the machine and the crane operators results in early fatigue of crane operators. Consequently they suffer from severe pain in neck, shoulder, and lower back regions after a short span of work, which results in poor health conditions and reduced human efficiency. All the crane operators face high risk of musculoskeletal injury due to poor work conditions. In one case a person suffered permanent damage to his spine and became unfit for any physically demanding activity. Haphazard placement of components and congested cabin resulted in unpleasant work environment. These problems subsequently resulted in low morale and reduced human efficiency among the crane operators.

3. Formation of Project Team

As the management was convinced about the usefulness of an improved redesign of the existing crane cabin in order to address the problems as stated, a project implementation team was formed. The project team consisted of five members from the company - Chief of Safety and Ergonomics, manager of CRM, three engineers from BAF shop, and three members from the institute - two faculty members and one research student. The team members from the company were responsible for providing the relevant data as required, initiating actions for project execution including purchasing of special materials and testing of prototype. The team members from the institute provided the knowledge and expertise as required for ergonomic evaluation of the crane cabin as well as assisting in the development of specifications of the redesigned crane cabin

4. Objectives of the Study

Keeping in view the above-mentioned problems, the study was undertaken with three specific objectives, viz., (i) ergonomic evaluation of the crane cabin worksystem, (ii) designing a new ergonomic crane cabin, and (iii) fabricating a physical model of the newly designed ergonomic crane cabin for design assessment and refinement. The project is an intense pilot study for ergonomic evaluation and design of the crane cabin with the scope limited to only BAF crane cabins.

5. Methodology

The crane cabin requires a systems approach for its ergonomic evaluation and redesign. As it was essential to address a number of issues of ergonomics, topics like anthropometry, work posture analysis, confined work space design, design of the visual environment, controls and displays were covered in this study.

The methodology used to meet the objectives as outlined consists of a number of steps viz., (i) analysis of the existing design, (ii) detailed redesign steps, (iii) prototyping and testing, and installation of newly designed crane cabin.

Analysis of the existing system requires execution of the following activities.

(a) Reconnaissance Study of the Cabin Worksystem

The information on several aspects of the existing cabin work system was obtained through a critical analysis of the existing components and through personal interview of the crane operators. The types of controls a crane operator may have, the devices required for signaling, and other components of the crane cabin were studied minutely. The different subcomponents of the cranes, mainly the controls and indicators were studied for their location, distances, and how a crane operator interacts with them.

The cabin space is very confined with not enough space for easy movement or easy ingress and egress to the chair. There is only standing space of any extra person in the crane cabin. The lighting at the work zone is inadequate for the visual requirement of the task. There are 21 crane operators in BAF, who are equally distributed among the 3 shifts of a day. In each shift 6 crane operators run the cranes with one crane operator on a weekly off. Each of the crane operators was personally interviewed with a questionnaire covering workspace, visibility, chair design, ease of use of controls, placement of controls, and ingress and egress to the cabin. The analysis of the crane operators' feedback gives the idea of features that eases the work of crane operators. Features like structure of the cabin, space inside the cabin, total window area, floor window area, visibility and speed of the crane reduces the stress and increases the productivity of crane operators. The chair installed in the crane cabin is the seat of a car. The car seat is designed for reclining sitting posture, while crane operators adopt forward bending posture during work. It increases the stress in the lumbar portion of the body by reducing the angle between the thigh and trunk. The crane operators' assessment clearly shows that the car seat provided as a chair in BAF crane cabin is totally unsuited for the work requirements of the crane operators.

(b) Anthropometric Study of Crane Operators

Knowledge of the anthropometric characteristics of the human is the prerequisite for a good understanding of the fit between the man and machine and the biomechanical design of any worksystem. An anthropometric study was carried out for the total population of crane operators in the BAF. In this study 23 body dimensions were measured out of which 19 are static and 4 are dynamic dimensions. The sample size of 30 people were taken which consisted of 21 crane associates and 9 ground associates, who were formerly crane associates. The measurements were done in a standard setup of straight sitting posture on an ergonomic adjustable chair. After the measurement of all the relevant dimensions, the 5^{th} percentile, 95^{th} percentile, mean, standard deviation, and range of each of the parameters were calculated. The relevance of each dimension with respect to various ergonomic characteristics of the work system is also mentioned.

(c) Misfit in Human-Machine interface

On comparison of the results of the anthropometric study with the component placement data of the crane cabin clearly identifies the misfit of the crane operator population with the existing work system. The misfit is measured as the difference between the ideal position of the control or the component and the existing position.. For the control position of the Longitudinal Travel, Main Hoist, and Auxiliary Hoist, 50^{th} percentile of population have 45 mm of misfit while 95^{th} percentile of population has misfit of 84 mm. Similarly, 95^{th} percentile of population has 136 mm of misfit for Main Cross Travel and 256 mm for auxiliary cross travel. The ACT control largest misfit values for direct distance of 510.67 for 5^{th} percentile population and 589.28 for 95^{th} percentile population. When the operator sits 50 mm ahead of the seat reference point, the misfits for all the controls increases. The largest increase in misfit is for 3^{rd} controller which gets behind the operator by 5 mm. for 50^{th} percentile of population the misfit with foot rest is 63 mm and with floor is 187 mm. while the LCD touch screen is at an offset of 190 mm from the 50^{th} percentile population eye height which is beyond the maximum forward reach of 100 percent of the population. All the indicators were indicated behind the operator, which were totally out of field of vision while working.

The misfit between man and machine results in many problems like awkward postures adopted, the stress induced due to awkward postures, the decrease in human efficiency.

(d) Postures adopted while working

The real-time observation of the crane operator while working was carried out to identify the postures adopted by the crane operators. From this study seven main postures were identified which were adopted by crane operators. Also, durations of the postures assumed and work-rest cycles of the operators were considered and analyzed. It was observed that sitting upright posture takes 14% of the total time, forward bending looking down posture takes 64% of the total time, bending right and looking down-right posture takes 7% of the total time, bending left and looking down-left posture takes 7 % of the total time, looking up posture takes 1 % of the total time, stretching out for the Walky-Talky/Mouse takes 1% of the total time, and reclining on the chair with back supported takes 6% of the total time.

The extreme work-rest cycle is observed during the night shift from 10pm to 6am when the crane operators continuously work for 4 hours without a break. This results in extreme stress levels among night shift crane operators. The study shows that work rest cycle depends on many factors like completion of heating cycles, work load, work scheduling, availability of operators and cranes, and shift. Our study shows that on an average crane operator works for 3:08:11 hours in A shift, 3:26:44 hours in B shift, and 4:00 hours in C shift.

(e) Pain occurrence

For getting the data about perception of exertion and pain by the crane operators during working, a modified Borg scale of range 1 to 10 was used. 100% of crane operators suffer from pain in lower back, neck, upper back, shoulders, arms, forearms, knee and legs. During the first working hour, the lower back, neck, and upper back pain starts and reaches to very high levels after 2.5 hours of continuous working.

This study clearly demonstrates that the existing crane cabin design does not provide any comfort, convenience of use or safety from high risks of musculoskeletal disorder. A crane cabin to be designed on ergonomic principles is necessary to be provided to relieve the crane operator of stress, pain and risk of any injury.

The redesign involves carrying out the following activities:

(a) Design for visibility from the cabin

The first phase of design was developing a conceptual model of an ideal crane cabin based on all the data which was gathered and analyzed in earlier phase of the project. The design parameters are maximized for their functions towards ease of operation for crane operators. This constraint exists because of design and layout of the shop and equipment. Another constraint that aggregates the problem extreme forward being is limited window area, particularly in floor. This second constraint is the focus of the present study of increasing the visibility of the work zone from the crane cabin and thus decreasing the extreme forward bending of the crane operators.

A computer model of an idealized cabin with the existing workshop was developed based on the drawings of the BAF layout and the proposed design of the ergonomic crane cabin. Then this computer model was simulated and studied from different parameters for work zone visibility from the crane operator's perspective. From this exercise the lines of sight and angles of viewing for different heights of stacks from different positions of the cabin were found out, which were then utilized for designing the window area of the cabin for maximum visibility of the work zone.

With the ideal crane cabin the first constraint of making cabin positioned directly over the stack on which work has to be performed is relieved by providing a larger floor window area. Also the view angles at the bottom and top of the stack increases to 16 degrees and 31 degrees for the stack directly below the cabin. There is an increase of 60% in the extreme position view angle which means lower bending for crane operator. A reduction in the bending of the amount of 240% for stacking at bottom and about 430% for the top was observed. This will reduce the cross travel of the cabin significantly and will thus save the time required for cross travel and will ultimately result in increase in productivity of the crane and crane operators. The view angles formed at the bottom of the stack is 37% and at the top of the stack is 57% with respect to the vertical axis which shows the reduction in the bending of the amount of 370% for stacking at the bottom of the stack and 570% for the top. Thus larger window area will reduce the need for the cross travel of the cabin resulting in time saving and increase in productivity. As the lines of sight to all the adjacent stacks are unobstructed, the operator in the cabin can see all the adjacent stacks without any need of repositioning of the crane cabin over those stacks. Similarly if the crane cabin is positioned between the stack 2 and 3, then there will be symmetrical view angles for stacks on both sides. The landing platform on the side in existing cabin obstructs the side visibility completely. In the new cabin the landing platform has been shifted from side to rear and entry inside the cabin has been made at an angle of 45%. This frees up the side space and improves side visibility.

(b) Design of chair for utility and comfort

The chair has been completely redesigned for the function of utility and comfort. Many new features have been added for assisting the operator to be able to work with ease. The chair is dimensioned for 50th percentile population based on our anthropometric study. Adequate adjustability is provided for chair features to accommodate the range from 5th to 95th percentile of study population. A V-shaped cut-out is provided in the pane of the chair right in front, in between the thighs. This feature enhanced the bottom visibility while the operator remains supported by the back support.

(c) Design of arm controller

The integrated arm controller has been totally redesigned on the principles of fit and reach. All the controls are brought in the easy reach and within the normal workspace of the operators. The array of 16 indicators cum reset buttons are brought forward to the operator. The walky-talky has been integrated with the left side arm controller with the voice activated mike for it is provided on the right side arm controller.

(d) Ergonomic placement of different components

All the components in the ergonomic crane cabin are assigned a specific place in the new ergonomic crane cabin.

During prototyping and testing, the following activities were carried out:

A physical model of the new design ergonomic crane cabin was manufactured after the first phase of design and shown to all the concerned people. All these concerned people were asked to evaluate the design and give feedback from their field perspective. Then a series of exhaustive meetings were held with all the concerned people and departments to refine the design. People involved during the second phase of the design were crane associates, operations management people, mechanical maintenance department people, electrical maintenance department people, design department of the company, and external manufacturing parties.

A number of mechanical maintenance issues such as crane safety buffers, glass cleaning aspects, and air conditioning aspects were taken care of before proposition of the final design of the ergonomic crane cabin.

Electrical maintenance was another issue which was taken care of for the complete and successful design of the ergonomic crane cabin. The issues considered are internal electrical wiring, relocation of junction boxes, and resizing of annunciation panel.

6. Conclusion

A number of lessons, such as how to minimize or remove the anthropometric mismatch, how to improve the visibility of workspace for a crane cabin operator in enclosed workspace, how to improve the layout of the components and controls within enclosed workspace, and to improve work posture minimizing risk of MSDs applying ergonomic principles have been learned.

With the installation and subsequent use of the new crane cabin, there had been a number of benefits, such as high morale and increase in enthusiasm of crane operators, reduction in work-related pain and injury risk, increase in comfort and efficiency of the crane operators, and increase in overall system productivity.