The contribute of ergonomic design in the interaction with control displays

Ramos, Sara  
E-mail: scramos@gmail.com  
Rebelo, Francisco  
E-mail: frebelo@fmh.utl.pt  
Gonçalves, Inês  
E-mail: nesgoncalves@gmail.com  
Simões, Hugo  
E-mail: simoesahugo@gmail.com  
Laboratório de Ergonomia – Faculdade de Motricidade Humana  
/ Universidade Técnica de Lisboa / Estrada da Costa – Cruz Quebrada / Lisboa / Portugal

ABSTRACT

This article presents a case study developed at a transformer production industry. The intervention focuses on the human-machine interaction during the realization of the activity and the consequences that derive when conception of the machine isn’t user centered developed. The context of the intervention, the tasks involved in the analyzed work situation and method aspects that lead to the intervention are described. The principal results of the analyses which show the need of a re-conception intervention of the workstation are also presented.

Keywords  
Ergonomic design, interaction, user, participative design

INTRODUCTION

The positive effects of ergonomic intervention in safety, well being of workers and on productivity is largely recognized in literature (Shikdar & Das, 1995). However the introduction of modifications to the work situation requires considering some aspects, like interventions in a ergonomic design point of view.

Although the automation and mechanization have had a huge progress some work situations are still very dependent on manual work (tasks such as, pulling, pushing and dragging). In this sense, the study of manual work stands of a topic of interest for the researchers (Looze, Urlings, Vink, van Rhijn, Miedema, Bronkhorst & van der Grinten, 2001), especially by the relevance of its consequences such as the muscular skeletal lesions.

The propositions concerning the prevention of these types of lesions can be divided in two big general orientations: interventions i) centered on the workman (ex: programs for workers resistance and physical condition improvement) and interventions ii) centered on the work situations transformations. From a general starting point that the ergonomic intervention should benefit not only the effects of one special working situation but also the reduction of risks that characterize the situation, we can place
the work presented in this article in the second orientation.

The ergonomic principals induce to an effective orientation to the workman bio-psycho-sociological characteristics. Thus the design of work situations consists in a commitment (Das, Wimpee & Das, 2002) between the workmen characteristics, the activity requirements and machinery.

The advantages of considering this commitment are recognized in literature, as well as the undesired consequences (for the workmen and for the organization) by the deviation of this commitment, specially the incidence of muscle skeletal lesions, the work accidents and even the low productivity.

But in spite of this recognition, the involvement of users lead to a concentration more on the evaluation of a specific instrument then on its conception (McClelland, 1995). Although the ergonomists reinforce the importance of developing specific methods which promote the participation of the users in the design process, this participation is not always considered, in particular when we refer to the design of machinery or work instruments in the industrial context.

The concept of participative design is based on the democratic participation between designers and users of a certain system (Lindgaard & Caple, 2001) in a jointed process. The participative character of the process allows for the opportunity of designing and altering decisions which will bring an impact on the final users work (Muller, 1993), optimizing his performance and reducing the negative consequences already spoken off.

In this article we present a still running case study that pretends precisely the transformation of a workstation according to the identified problems, for a more appropriate adaptation to the user.

The purposes of this study are: i) realize an ergonomic analysis of the so called workstation; ii) understand the workmen interaction with these equipments throw different methodological instruments; iii) identify the interaction difficulties between the workmen and the equipment used during the activity; iii) present propositions of intervention that consider the user point of view in a participative logic.

In the following sections will be described the intervention context and the activity develop in this working situation; the methodological procedures adopted in the field and the principal results obtained.

**CASE DESCRIPTION**

The context were this intervention was developed consists in a large transformer production industry. The activity analyzed is the conception of inductors (bobbins) that form an essential component for each one of the final products.

**Task description at the inductors (bobbins) production workstations**

Generally, each inductor is made of 2 layers: (1) the interior layer of low voltage (LV); (2) the exterior layer of high voltage (HV). The layer of LV can be made with two types of different materials that determine completely different tasks: bar; band. The layer of HV can also be divided in two types, which have similar tasks: HV bar or thick wire; HV of medium wire or thin wire. All these materials are made of copper, rapid conductor of electricity.

These 4 types of layers are made in 4 types of different machines, being that the machines which produce layers HV depend on the layers LV produced previously. In all there are 11 machines: 2 LV band; 2 LV bar; 2 HV bar or thick wire; 5 LV medium wire or thin one.
Generally speaking, the production of HV inductors is divided in 3 big tasks, and each one is divided into sub-tasks according to the following table:

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Preparation and positioning of the inductor in the machine</th>
<th>Coiling</th>
<th>Ending and extraction of the inductor from the machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-tasks</td>
<td>Preparation for transportation</td>
<td>Coiling of the wire</td>
<td>Preparation for transportation</td>
</tr>
<tr>
<td>Transportation</td>
<td>Isolation placement</td>
<td>Channel placement</td>
<td>Extraction of the inductor from the axle</td>
</tr>
<tr>
<td>Positioning of the inductor in the axle</td>
<td>Strips placement</td>
<td>Transportation of the inductor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plugs placement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Welding</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – Tasks and Sub-tasks for the production of HV inductors.

Generally speaking, the operators have to initially place the LV inductors in the coiling machines (Preparation and positioning of the inductor in the machine). The procedure of coiling consists mainly in the coiling of the wire in different layers considering that the wire must be coiled with the minimum spaces in between possible. Between each layer a isolation material is placed which prevents the overheating (and possible short-circuit) of the transformer. The placement of strips, when it’s necessary, it’s done twice by layer, and the ends of the inductor; the placement of plugs requires sometimes welding between the copper wire ends. Placing channels on the inductors is a rare process that implies very little time spent. When the inductor is ready, the workers still have to take them out of the machine, being a fairly quick process. The coiling task is, so, the one which occupies more the workers, and the sub-task of coiling the wire is the one that takes longer.

Concerning the more relevant organizational aspects, these workstations function in 2 shifts of 8 hours each. Concerning the breaks, there is an official break, but more breaks can be arranged according to the workers necessity.

**METHOD**

**Sample**

Concerning the sample of this study, we considered two types:

- **Sample 1:**
  
  Sample 1 corresponds to the total population of coiling workstations, with 16 workers, 6 of them are men are the other 10 women. The age of the majority of these workers is between 31 and 50 years-old, having 11 to 20 years of working experience in coiling.

- **Sample 2:**
  
  Sample 2 corresponds to a fraction of sample 1, more specifically to workers who produce HV type inductors, a total of 9, all women. Concerning the age and work experience it’s very similar to sample 1.
Tools

Free observation with informal interview

The purpose of this phase were essentially to know the different type of tasks linked to all the coiling procedure, to contextualize them with the problematic and, consequently, identify those that could be the most critical situations of the all process. During the 2 shifts free observation was used. Simultaneously some questions were made which helped us to clarify some doubts associated with the work procedures observed.

This analyses include 16 workers, that were distributed by 11 working stations(sample 1).

Questionnaire with interview

The questionnaire goals were: identify the body parts more affected, as well as the symptoms more frequently associated; identify risk factors which lead to the previously referred symptoms; identify the more problematic machines and/or inductors.

This tool was elaborated according to the results of the free observations and informal interviews, divided in two big parts: (1) symptoms questionnaire; (2) workstation general questionnaire.

The workstation general questionnaire (2) had a wide range of questions related to:
- accidents or incidents occurred until then;
- the work posture;
- the physical elements that were part of the workstation ( ex: chair, screen, control panel, etc.);
- the tools used during the activity;
- the use of individual protection equipments (IPE´s);
- the type of inductors produced;
- the machines used for the production of inductors;
- the work shifts;
- the breaks taken;
- the workers productivity;
- the realization of overtime;
- the execution of other tasks others than the ones of coiling;
- the characterization of the sample (ex: age and sexual gender).

This tool was applied to all workers (sample 1). So that the answers were as close as possible to the reality of the work, we applied the questionnaire in the real work situation during the workers activity. This option was taken considering the nature and rhythm of the activity so that it wouldn´t interfere with their performance.

OCRA checklist and HAL

These two tools were grouped under the same topic, seeing that its application had a big common goal: identify the workers more problematic task, concerning their risk of
developing muscular skeletal lesions (MSL) in their upper limbs.

The goal of the Ocra checklist application was to identify the highest risk tasks considering the following risk factors: repetition, strength, posture, lack of recuperation periods and other additional factors. With the application of HAL we intended to determine whether the activity observed involved risk of MSL, but only for the distal upper limbs (hands).

For the application of these checklists the activity of 3 workers was recorded (they were producing HV inductors, i.e., belonging to sample 2). Either the OCRA checklist or the HAL were applied through video, by two researchers. The fact that these tools were applied by two people is justified by the necessity of having a similarity of results, guaranty of their viability.

The workers that were watched produced different types of inductors (inductor 1, 2 and 3), especially by the thickness of the wire coiled, which led to different *modus operandi*.

The tasks analyzed and compared, relating to HV inductors, were:
- Ending and extraction of the inductor from the machine;
- Coiling;
- Preparation and placement of the inductor in the machine.

*RULA and Strain Index (SI)*

These two tools are also associated, seeing that their joint application allowed to identify the 3 more demanding sub-tasks for the workers in the Coiling task (HV inductors), in a range of 6 sub-tasks.

Specifically, the goal of the application of RULA was to classify the risk of MSL in the superior limb related to the sub-tasks observed, essentially based on the posture factor. The same goal was intended with the application of the SI but according to other type of variables (intensity, duration and repetition of the effort; posture and velocity of work; daily duration of the tasks).

Concerning the selection of the tools we decided to apply Ocra checklist and HAL firstly because they are more generic since their questions didn’t report to a specific situation, as it happens with RULA and SI. These two last checklists refer to a specific posture or a movement.

Like the previous checklists, these were also applied recurring to video recorded previously by the same to researchers.

The sub-tasks observed, from the Coiling task, were the following:
- coiling of the wire;
- isolation placement;
- channel placement;
- strips placement;
- plugs placement;
- welding.

*Behaviour Video*

After identifying the more problematic sub-tasks it was necessary to make a more
deep analysis so we could identify which behaviors of those sub-tasks could be the source of the complaints and symptoms of the workers. For this purpose it was applied the Behavior Video. Generally speaking this is an application that registers the number of times that a worker has a specific behavior as well as its partial and total duration, during a work cycle.

Once more we used the videos recorded to proceed to the application of this tool. Because it takes double the time of the video to analyze the video using Behavior Video, only one specialist did it, and the results were analyzed later by the work team.

6 different behaviors for each sub-task were analyzed which made a total of 18 behaviors per video, as shown in the following table:

<table>
<thead>
<tr>
<th>Behaviors analyzed with Behaviour Video</th>
<th>HV inductors</th>
<th>1, 2, 3</th>
<th>1, 3</th>
<th>1, 2, 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-tasks</td>
<td>Coiling of the wire</td>
<td>Isolation placemante</td>
<td>Strips placement</td>
<td>Plugs placement</td>
</tr>
<tr>
<td>Behaviors</td>
<td>Regulate the machine</td>
<td>Regulate the machine</td>
<td>Regulate the machine</td>
<td>Regulate the machine</td>
</tr>
<tr>
<td></td>
<td>Join wire (under)</td>
<td>Pull (internal)</td>
<td>Pull (internal)</td>
<td>Pull (internal)</td>
</tr>
<tr>
<td></td>
<td>Join wire (above)</td>
<td>Pull (external)</td>
<td>Pull (external)</td>
<td>Pull (external)</td>
</tr>
<tr>
<td></td>
<td>Hammer the wire</td>
<td>Glue</td>
<td>Glue</td>
<td>Glue</td>
</tr>
<tr>
<td></td>
<td>Hold the wire</td>
<td>Cut</td>
<td>Cut</td>
<td>Cut</td>
</tr>
<tr>
<td></td>
<td>Follow the coiling</td>
<td>Holding isolation</td>
<td>Join and hammer the strip</td>
<td>Hammer the plug</td>
</tr>
</tbody>
</table>

Table 2 – Behaviors analyzed with the tool Behaviour Video.

RESULTS

From the two first phases of analyze (Observation, Interview and Questionnaire), we can reach the following conclusions:

i) The workers who produce HV inductors have the biggest number of complaints;

ii) The body parts more affected are: right wrist, lower back, cervical and right hand;

iii) In the right hand, the workers complaint especially about the thumb, indicator and middle fingers;

iv) From a user point of view, the reasons by which these symptoms occur, its due to various behaviors they adopt during their activity (like join or hammer the wire during its coiling), being the posture also a risk factor to the development of MSL.

After realizing that the more problematic workstations were those who produce the HV inductors, we proceeded to the application of the checklist OCRA and HAL, having analyzed the 3 big tasks of the Coiling process.

Concerning the results of the OCRA checklist, we concluded that in the various workstations analyzed (HV inductors production) the Coiling task is the most problematic, obtaining always values which correspond to a high risk of MSL. Also through the HAL it was confirmed that the more problematic task is Coiling, verified by the high values of risk on the right hand.

This way, we narrowed our analyses to the sub-tasks of the task considered more problematic until then. Through the tools RULA and SI clearly it was verified that the
sub-task “coiling of the wire” is the more painful (RULA ≈ 7), followed by “plugs placement” (RULA ≈ 5.5), for the 3 types of inductors. There was, however, some sub-tasks that didn’t obtain consensus: “strips placement” (RULA ≈ 7) had a quite meaningful value only on the type 2 inductor; the “strips placement” (RULA ≈ 4) was the third more problematic sub-task on the type 1 and 3 inductors.

Concerning the results of the SI, once more it was clearly verified the biggest risk of MSL in the right upper limbs.

After decomposing each one of these sub-tasks in behaviors, we proceeded to its detailed analyses, either by the number of repetitions, either by the total time of exposure to the respective postures, by work cycle.

We came to the conclusion that, concerning the relative frequency of the behaviors, the more meaningful are:

i) Regulate the machine, characterized by a posture of trunk torsion to the left, and using the left hand fingers to press the buttons, with the respective upper limb without support;

ii) Pull (external), which corresponds to the act of pulling all the elements that are external to the machine, especially the tape. In this case it happens that besides the repetition of this behavior it is also necessary some strength to cut the tape, leading to a bigger effort in the hand (thumb, indicator and middle finger);

iii) Glue (the tape), being related to the previous item. In this behavior the workers use either the indicator or the thumb (increasing this way the daily effort in these areas);

iv) Hammer the wire, normally used in replacement to the use of the stick (used to join the wire). This behavior is characterized by the use of a hammer on the inductor, with the right hand.

Regarding the relative duration of the behaviors, it was verified that some were more constant during the shift, such as:

i) Join the wire (especially under), which implies the use of a wooden stick to join the wire during the coiling, as well as the application of considerable effort for its efficacy. For that the worker is subjected to the machine vibrations due to the coiling of the wire, using for that purpose the right hand.

ii) Hammer the wire;

iii) Regulate the machine.

CONCLUSION

The results described in the previous section reveal the necessity of a re-conception intervention of this work situation.

In a follow-up, some intervention proposals were conceived on the most problematic workstation which are currently being implemented.

Generally, the intervention proposal focuses on 3 aspects of the workers interaction with the workstation system which seem problematic:

i) replacement of the existing manual tape device responsible for the “Pull (external)” action, with a automatic tape device;

ii) change of the machine’s control device, specifically the transfer of the
function from the control panel to a device located near the workers hand, which allows a greater precision in the machine’s regulation and also reduces the number of actions of: “hammer the wire”, “join the wire” and “regulate the machine” (avoiding the use of the wooden stick);

iii) transformation of the workstation, in particular the work-height and the chair use by the workers, with the objective to improve the interaction with the machine.

Concerning the automatic tape device (i), one of the discussions of the multidisciplinary team working on this project, focused on its location, since on one hand it couldn’t interfere with each workers normal activity and on the other it should be in an optimal reach space, considering the high frequency of use of this device. Furthermore, it was required that from the worker to pull the tape (either with the left hand fingers or the right ones). In this way it was suggested the introduction in the machine of a movable and flexible arm to the right of the workers to place the automatic tape device.

As for the wire fall distance regulation manual device (ii), the type to be adopted was initially questioned, but it was verified that the best would be to choose some sort of bilateral joystick, activated by two pressure sensors: one on each side. So, as there are activated they should send out visual and kinaesthetic feedbacks, so that the workers are aware of their activity. Considering that the objective of this alteration was to minimize, at least, three risk behaviours (essentially by its repetition and duration), its expected that this will be a “tool” of regular use. This way it should be placed so that the worker wouldn’t adopt risk postures. As there is a chair at the workstation, possibly with an armrest, we thought of placing the joystick connected to the end of the armrest, giving each worker the choice of using it on the right or left hand. One of the biggest advantages associated to this device consists of allowing the workers to have a direct perception that their action (moving the joystick to the left or to the right) has a reaction of the machine/wire in the same direction, respectively.

As it was expected, all these changes depend on each other, establishing necessarily regular relations of commitment. The questions related to the work-height, and with the chair (iii) were no exception. The existing chairs don’t allow height regulation and don’t have lumbar support (just a dorsal support) which leads to uncomfortable postures, especially because the operators have a need to sit forward so their feet reach a pedal. This way and considering the dimensional and morphological difference among the workers, it was suggested the acquisition of proper chairs, in which seat height variation equals the footrest height variation, obviously with the pedal placed above it. Therefore, we believe the workers will adopt more comfortable postures, due to a better and more convenient work position in relation to the inductor, using as well both back supports (lumbar and dorsal).

Thus, these interventions are currently being implemented, so it’s not yet possible to evaluate the outcome of this intervention. We are looking forward to a phase of their introduction in collaboration with the workers, guarantying that they will continue participating in this process of change, since the conception to the implementation of solutions.

REFERENCES


