

ERGONOMICS CONTRIBUTION IN MAINTAINABILITY

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Abstract:

The objective of this paper is to describe an ergonomics contribution in maintainability. The economical designs, inputs and training helps to increase the maintainability indicators for industrial devices. This analysis can be helpful, among other cases, to compare systems, to achieve a better design regarding maintainability requirements, to improve this maintainability under specific industrial environment and to foresee maintainability problems due to eventual changes in a device operation conditions. With this purpose, this work first introduces the notion of ergonomics and human factors, maintainability and the implementation of assessment of human postures, including some important postures to perform maintenance activities. A simulation approach is used to identify the critical posture of the maintenance personnel and implements the defined postures with minimal loads on the personnel who use the equipment in a practical scenario. The simulation inputs are given to the designers to improve the workplace/equipment in order to high level of maintainability. Finally, the work concludes summarizing the more significant aspects and suggesting future research.

Key words: ergonomics, maintainability, human posture, human factors, ALBA simulation

INTRODUCTION

Technologies for automating manufacturing systems and processes played a key role in manufacturing facilities in the last decades; however it is impossible to remove human involvement in some of the manufacturing processes and still requires manual handling due to the flexibility and the skill of human operators. Some of these handling tasks deal with heavy physical loads or uncomfortable postures, which might result in stress or overload in the muscles and joints, and further generate potential risks for musculoskeletal disorders (MSDs) [1, 2]. In the manufacturing facilities, the design of complex mechanical systems must be carried out easing the tasks of operators who assemble and maintain them. To achieve these objectives, there is a need of detailed set of working instructions ensuring an effective manufacturing process and a safe work environment.

Digital Human Modelling (DHM) techniques have been introduced to test, validate and improve the working instructions, improve both the design of workers' task and of the product, taking human as the center of the work design system [3, 4, 5, 6, 7]. A human centric approach allows validating the workspace design, assessing the accessibility of an assembly design, reducing the production cost, and the risk of MSDs as well. Human Centred product design [8, 9] is considered an effective means to fulfil the customization trend and it should be conducted through the life cycle as much as possible. In particular in the early stage of product development like Design for Manufacturing (DFM) [10, 11] or Design for Assembly (DFA) [12, 13] ergonomic issues must be seriously taken into account.

During the product design, designers are mostly focus on the functionality of their product. These products

(industrial and private consumers) have an interaction with the intended users at the moment when they are in function or /and when they are in maintenance operations in order to keep them in function. Nowadays industrial products are so complex and complicated that a group of designers (electrical, mechanical, hydraulic, etc.) will be engaged only for one product.

In order to have high quality, durability, reliability and ease of use for each product it depends on up to what extent designer contemplated the end users' physical and mental abilities as well as end users limitations. Fulton Suri, (2000) [14] highlighted that today's designers work at a distance from their widely diverse communities of users. In many cases, they are expected to rely upon other specialist functions, such as market research and ergonomics, to act as interpreters of peoples' needs and desires. It is not expected products designer should have a thorough knowledge regarding the end users abilities and limitations. These areas are a domain or knowledge base of ergonomist. Haslegrave and Holmes (1994) [15] argued that it is important for ergonomists to understand the main aspects of engineering design, both related to process, product and business constraints, as well as it is important for design engineers to get some formal education in ergonomics, so that both professions understand each other's approach to design problems.

User centred system-product design logic make an important conceptual distinction between purely technical design and ergonomically design. So, any divergence or distance from this concept make end users to adapt themselves more to the system or product functions rather than design engineers together with ergonomist try to adapt

their system or products to the end users abilities' characteristics.

O'Neill [16] described one of the maintainability aspects during design process is involvement of safety engineer in the maintainability management.

Maintainability in general is a procedure in the process for design of system or product in which designers need to go through with the aim of having more maintainable and reliable, high quality, easy to use and higher durable functionality of their design in order to meet in-tended user requirements. The process for product design is explained in Figure 1.

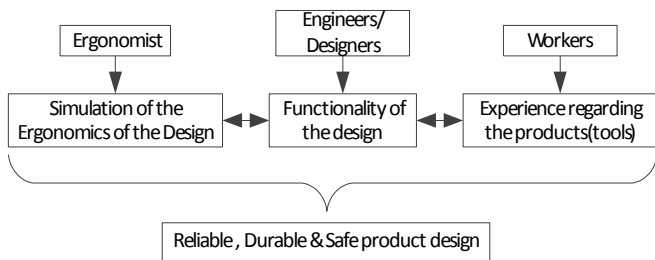


Fig. 1 Product design work flow

The content flow of this manuscript is arranged as follows. After introduction, in the second part a brief literature review is presented, including the definition of the main concepts, which are later used in the paper. Afterwards, in Section 3, the maintainability indicators and maintenance levels are presented. Then, Section 4 the methodology to assign the maintainability attributes from device design perspective, maintenance staff and work conditions perspective and logistics support perspective is illustrated. Consequently, in Section 5, the implementation of the methodology is explained and the corresponding results are also presented. Section 6 discusses the results obtained from the analysis. Finally, the work concludes summarizing the more significant aspects and suggesting future research.

ERGONOMICS AND HUMAN FACTORS

Human factors or ergonomics stands as a multidisciplinary science. It applies for distinction between human abilities concerning physical as well as mental and limitations at the time when human is used or being involved in system operation or use of manufactured products.

Because of being multidisciplinary science Human Factors and Ergonomics Society introduce five different definitions [17]:

1. Definition from Professional Societies,
2. Definition from Scientific Literature,
3. Definition from Government Agencies,
4. Definition from Industry;
5. Definitions from open Sources.

All these definitions are shared in the fundamental principle that ergonomic (or human factors) is a method for investigations of interactions between humans and system in order to evaluate compatibility of: design, task, products, technologies and system to the human biological, physiological, psychological and social characteristics. They are also shared in optimizing human performance as well as enhancing health and safety in the environment they are engaged.

Ergonomics deals with human capacities by considering of their work environment. It deals with fitting the task to

the man not vice versa as defined by Wickens (1984) [18]. There are several tools in ergonomics that can be used in order to evaluate human capacities to the work system requirements. Among them is participatory ergonomic. Brown, (2002) [19] describes; participation and participatory practices are the principal methodologies in the design and analysis of work system. Cotton (1993) [20] defines the term "employee involvement" as a participative process to use the entire capacity of workers, designed to encourage employee commitment to the organizational success. Wilson and Haines [21] pointed out participatory ergonomics can be regarded as philosophy, an approach or strategy, a program, or a set of techniques and tools. They defined it as the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both process and outcomes in order to achieve desirable goals. The role of ergonomist participate in the manufacturing process is shown in the Figure 2.



Fig. 2 Role of ergonomist participation

MAINTAINABILITY

Dhillon [22] defined the maintainability, which refers to the measures taken during the development, design, and installation of a manufactured product that reduce required maintenance, man-hours, tools, logistic cost, skill levels, and facilities, and ensure that the product meets the requirements for its intended use.

O'Neill [16] has described the maintainability as; "The relative ease and economy of time and resources with which an item can be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. In this context, it is a function of design." He stated maintainability and reliability test and analysis usually follow performance analysis in the design process. One of the maintainability aspects during design process is involvement of safety engineer in the maintainability management. The concept of "safety is first" is believed in all branches.

In Handbook of Department of Defence [23] stated that "In designing for maintainability, the maintainability engineer must be constantly aware of the relationship between maintainability and safety, also maintainability engineer must collaborate with human factors engineer in order to considering human factors during design efforts. It is also

mentioned maintainability is included as a subset of human engineering. Safety includes designing the product and maintenance procedures to minimize the possibility of damage to the product during servicing and maintenance, and to minimize the possibility of harm to maintenance and operating personnel.”

In many industries design of products are for private and/or industrial consumers. For both, designers in European countries follow the CE (Conformity marking/Conformité Européenne) marking in order to clarify their products complies with safety directive for intended users.

SIS-ISO/TS 16949:2009 [24], is the standard that supplier for car industries should follow it in order to be certified as car parts supplier. Shortage of that causes deviation or in case of major deviation it can be result to cancelling certification.

ISO 9001:2008, Quality management systems-requirement which refers to work environment defines; “the organization shall determine and manage the environment needed to achieve conformity to product requirements”, in that the term “work environment relates to those conditions under which work is performed including physical, environmental and other factors (such as noise, temperature, humidity, lighting or weather). In this standard there is specific requirement; “personnel safety to achieve conformity to product requirements as: product safety and means to minimize potential risks to employees shall be addressed by the organization, especially in the design and development process and in manufacturing process activities”.

As it reported in “Fatal Injuries Among Grounds Maintenance Workers – United States” [25], a total of 1,142 grounds maintenance workers (GMWs) were fatally injured at work during 2003-2008, an average of 190 each year. A study by AFIM [26] (French association of maintenance engineers) on a population of maintenance workers shows an occupational disease rate 10 times higher than for other workers.

Even though designers following all standards for their products or systems, the above reports reveals maintenance people are more in danger compare with other workers. This indicates designer unintentionally trap in a Black Hole concerning to safety aspects in their design, that is “They do not know what they do not know”.

In order to minimized or eliminating the risks as it mentioned earlier using participatory ergonomics as a tool in the design and development process it is not only improving safer work environment also will result the increasing of safety culture among designers. Participators can be; designers, representative of workers union, skilled operators and ergonomist or human factors engineer.

As maintainability designers use different simulation’s programs for testing the functionality of their future product(s), ergonomics engineers can do necessary simulations concerning physical workload (products heaviness, posture taken, calculating biomechanical forces and moments in different part of body), inventing of risks (fall from height, cutting fingers, pinching finger under assembly or/and disassembly of part(s), slippery floor, electrical shock). Through pre-simulation, participators can start to develop a Standard Operating Procedure (SOP) as described by Ali Rastegari [27]. He stated, “An SOP is a written document or instruction detailing all relevant steps and activities of a process or procedure”.

For each operation of task this group should provide a standardized working process for maintenance operators in a way that where to start and how to end the work. Standardized work provides great benefits such as: stability in process, clear stop and start points for each process, organizational learning, audit and problem solving, employee involvement, kaizen and training operators as describe by Pascal Denis [28] in his book “Lean Production Second Edition”. Figure 3 explains the overall picture of the ergonomics contribution in maintainability.

METHODOLOGY

When the process of maintainability design is carried out, new risk analysis should be performed and it should be compared with the simulation phases whether they discover new risk or not. Each identified risk should delegated to responsible person(s) with due date. Responsible person(s) have three alternatives; eliminating risk, minimizing risk or accepting the risk as it is. In the situation of second and third alternative relevant personal protective equipment and safe work instruction must be prepared. Regarding physical workload is the same, ergonomist should find technical lifting aids, other aid equipment or redesigning work cell structures.

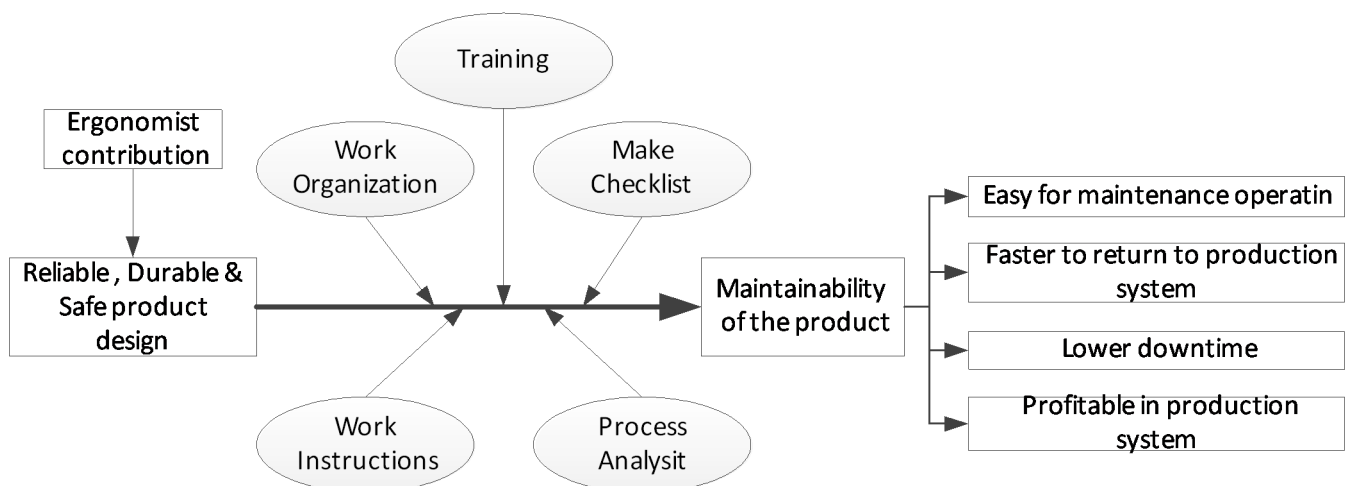


Fig. 3 Ergonomics contribution in maintainability

Concerning physical workload at different taken postures, it is necessary to calculate biomechanical forces and moment to the most critical parts of the body.

One way during design process in maintainability is that ergonomist use different simulation program which among them is ALBA biomechanical analysis program. This program is developed at Linköping University in Sweden in 1994. ALBA has different functions and has eight countries anthropometrical data both for women and men. Among its anthropometric data two of them concern with body segment weight and their centre of mass locations.

Chaffin, Andersson and Martin in "Occupational Biomechanics [29] describe how to calculate body segment mass which is a product of:

$$D = m/V = (W/g)/V \tag{1}$$

Where D is mass per unit volume (g/cm³), m is the mass of body segment (g or kg), V is the volume of water displaced (g/cm³), W is the weight of the body segment (N) and g is gravitational acceleration constant (m/sec²).

$$\text{Segment mass} = \text{Segment Volume (cm}^3\text{)} \times \text{Segment Density (g/cm}^3\text{)} \tag{2}$$

Knowing these two parameters (body segment weight and its centre of gravity) it helps to calculate the biomechanical stress (forces and moments) in some critical parts of the body. These critical parts are; elbow, shoulder, L5S1 (the lowest of the lumbar spine's of five vertebrae and the first vertebrae of the sacrum), hip, knee and ankle.

IMPLEMENTATION AND RESULTS

In ALBA compendium it is stated if the compression in spine shows the force between 2500-4500 Newton it increase the risk for back injury and significantly increased risk for back injury when the compression exceeds over 4500 Newton.

At first, the existing working conditions are considered. Figure 4 shows a simulation without any hand load in situations; squat and stoop postures.

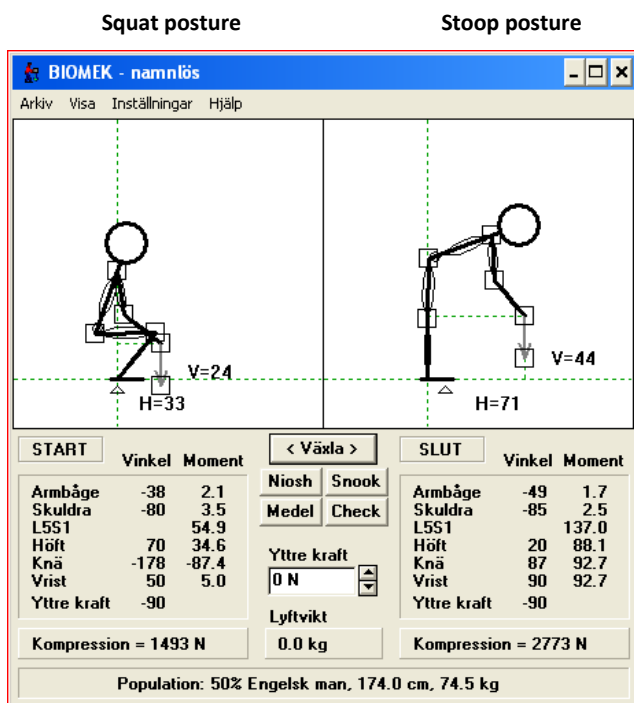


Fig. 4 Role of ergonomist participation

In these simulations it assumed asymmetry angle in sagittal plane is 0. In the ALBA anthropometries data, body segments weight for head, neck, hand and trunk is 63.5% of the total body weight. For below simulation, English men at 50 percentile were selected. In Figure 5 and 6 it simulated hand load for 5 and 10 kg for the same postures. The results in Table 1 show even there is no load in hands based on only body segments weight having stoop posture is in risky zone and significantly increasing stress on moments on L5S1 and back compressions when hand load is 5 and 10 kg respectively.

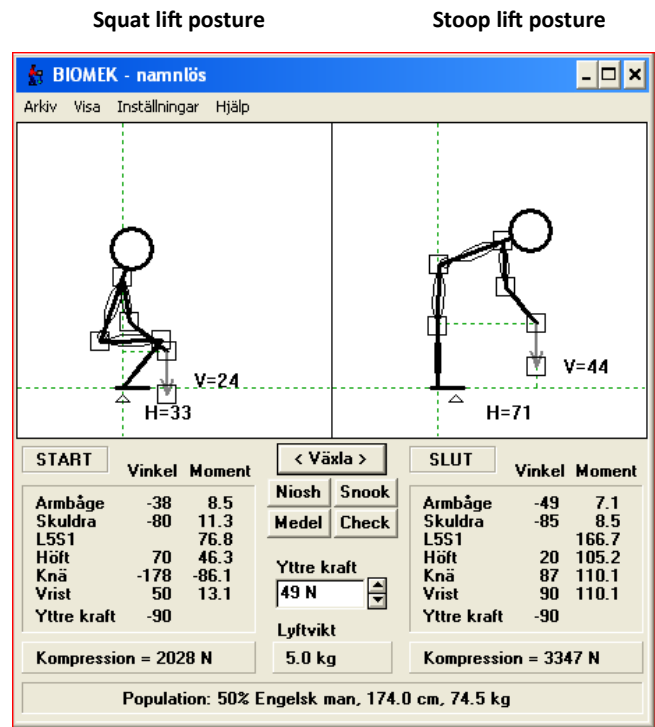


Fig. 5 Lift object is 5 kg

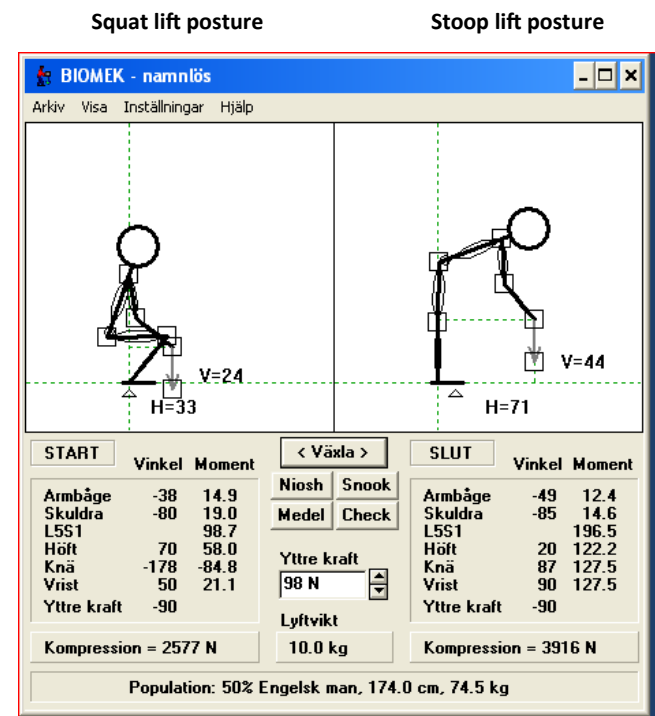


Fig. 6 Lift object is 10 kg

Table 1
Existing stresses for loading conditions

| | Squat posture | | | Stoop posture | | |
|----------------------|---------------|------|-------|---------------|-------|-------|
| Hand load weight | 0 kg | 5 kg | 10 kg | 0 kg | 5 kg | 10 kg |
| L5 S1 (Nm) | 54.9 | 76.8 | 98.7 | 137 | 166.7 | 196.5 |
| Back compression (N) | 1493 | 2028 | 2577 | 2773 | 33477 | 3916 |

Table 1 shows the existing taking squat posture compare to stoop posture maintenance operators have less stress moment on L5S1 (Nm) and back compression (N) in all three simulations phases.

In the shop floor the existing working conditions at the working place were observed and better arrangement of working place with a better positioning is suggested. The improved work place environment is designed in a way that operators can have standing posture instead of squat situation the stress moment and back compression can be reduced. The simulated results of the new working environment with the new posture for the stresses with different loading conditions are shown in Figure 7, Figure 8 and Figure 9. The Table 2 summarise the stress conditions for the new posture.

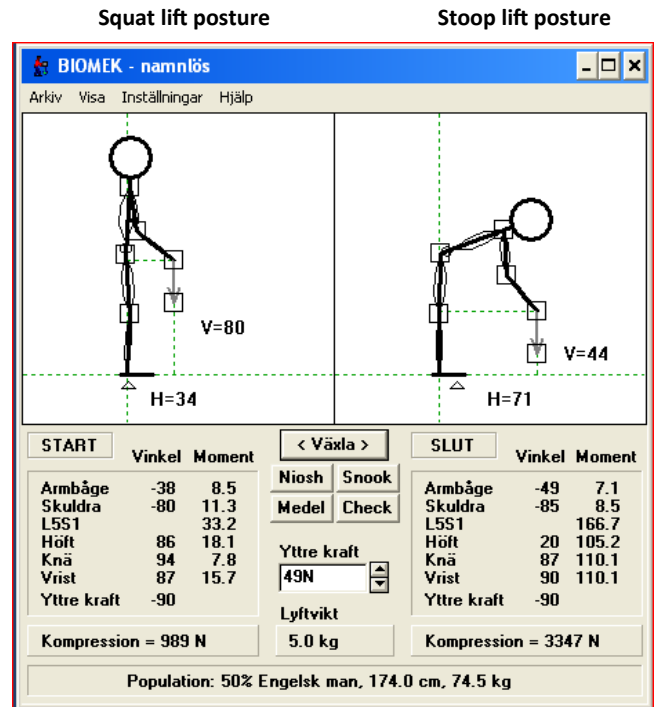


Fig. 8 Lift object is 5 kg (new posture)

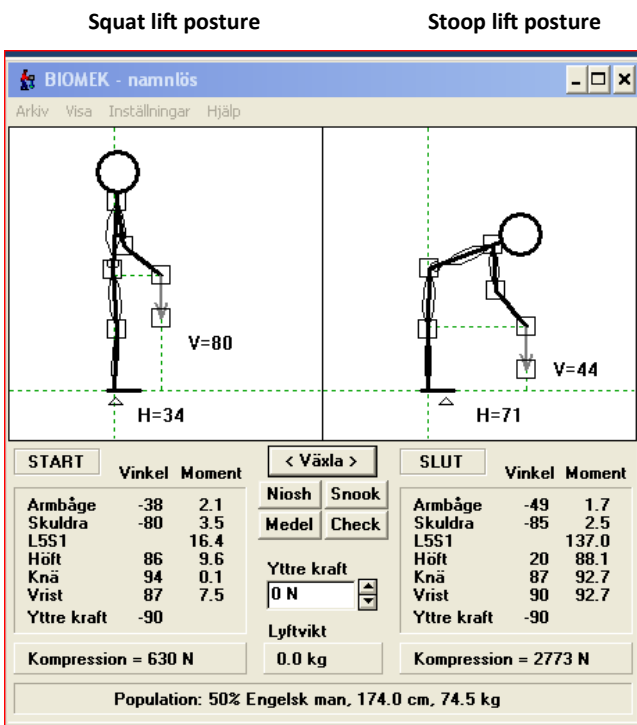


Fig. 7 Lift object is 0 kg (new posture)

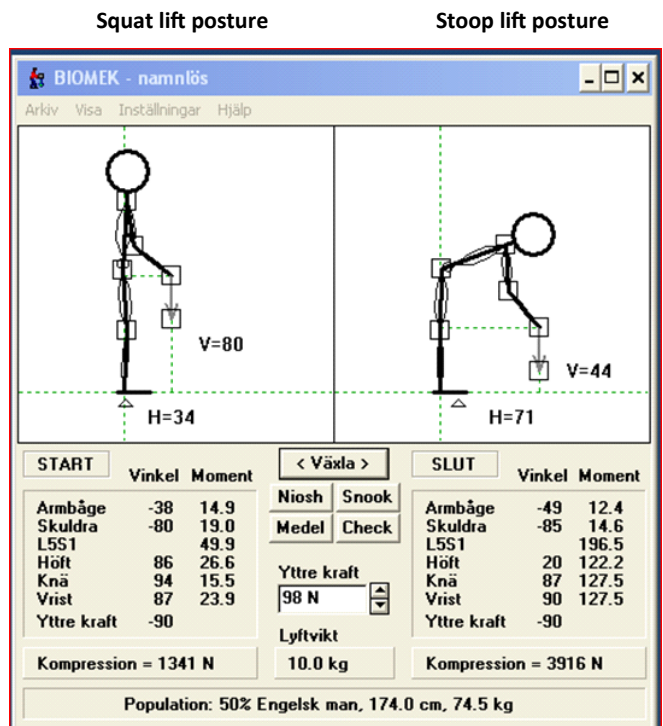


Fig. 9 Lift object is 10 kg (new posture)

Table 2
Improved loading conditions

| | Standing posture | | | Stoop posture | | |
|----------------------|------------------|------|-------|---------------|-------|-------|
| Hand load weight | 0 kg | 5 kg | 10 kg | 0 kg | 5 kg | 10 kg |
| L5 S1 (Nm) | 16 | 33.2 | 49.9 | 137 | 166.7 | 196.5 |
| Back compression (N) | 630 | 989 | 1341 | 2773 | 3347 | 3916 |

DISCUSSION AND CONCLUTIONS

The newly introduced “Squat lift posture” reduces the stress levels (L5S1 and back compression) of the workers by 50% (approximately). Therefore, the newly designed work place has improved the working levels improving the maintainability aspects.

With the purpose of optimizing human performance in maintainability design procedure, establishing a group of designer, ergonomist and skilled operators who will have interaction with products is a key for the success to have a good designed product. Designers solve problem by technical manual(s) and aids while ergonomist and skilled oper-

ators prefer analytical and technical way base on their knowledge and experience.

Ergonomist contribution in maintainability design process can be in two platforms; Micro and Macro Ergonomic. Micro ergonomic deals with technical aspects of design; workplace, tools, software, while Macro Ergonomics deals with instruction or regulation of production system, work organization, organizational design (complexity, formalization and centralization) and function allocation.

In the maintainability design process both designer and ergonomist need to understand each other more in order to solve both technical and human limitation problems. Successful design needs collaboration between maintainability designer and ergonomist.

This collaboration lead higher adaptability and flexibility of designed product to the intended users, lower cost for maintenance operation, more efficient maintenance can results faster return to operation or service consequently decreasing downtime, and lower cost of ownership over the product's life cycle.

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