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MARIBOR

DESIGN AND INTRODUCTION OF A CHAIRLESS CHAIR EXOSKELETON

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Signed Vijin Venugopal, am the author of the diploma thesis titled *Introduction and application of Exoskeleton chairless chair*, which I wrote under the mentorship of mag. Jože Ravničan, uni. dipl. inž. str..

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ABSTRACT

The research of this diploma thesis is about the design and introduction of ergonomic chair-less chair. This topic really helped me to get more connected with the CAM-CAD software, ergonomics, human health anatomy and work safety and environmental protection. I took this topic because the company has both an assembly section and a production section. In both sections most of the work is done in a standing position. According to medical science, prolonged standing results in inflammation in veins and causes the joints in the spine, hips, knees, and feet to become temporarily locked. This will improve muscle soreness, lower back pain issues and other discomfort in the employees, thus affecting the productivity and well-being of that person. So, the potential problems are less production, more time to attain targets, and more sick leaves. Thus, the decreased productivity of the workers leads to reduction in production and extra costs and puts the reputation of the company in turmoil.

Introducing this ergonomic chair will help them to work with ease, minimize the number of sick days and decrease capacity constraints. The chair is mounted to workers legs and the person can move with it and sit on it freely and work in ease. It also helps to increase the productivity of the worker and provides a tireless working atmosphere. This will be a replacement for a normal chair and thus we ensure better space management. Other-than that we can use this where the normal chairs cannot fit.

This is a theoretical diploma work with a descriptive working method. A systematic approach of searching the literature was used. A detailed explanation about ergonomics and its branches is explained, and the advantages and future possibilities of exoskeletons are also explained. A narrative review was undertaken in order to discover the increase in productivity and workability of the worker in connection with ergonomics. In this section, the methodology used for the literature search is described.
The obtained research results are expected to increase the productivity and workability of the worker. It is expected that there will be a 20- 25% increment in the workability of the employee and 50% less in both physical and mental fatigue of a worker. This research also provides insights into the future scope for mechatronic exoskeleton and brain-controlled prosthetics.

Keywords: *Ergonomics, Exoskeleton, brain-controlled prosthetics, mechatronics*

Povzetek

Raziskava v tej diplomski nalogi se nanaša na oblikovanje in uvedbo ergonomskega stola brez stola. Ta tema mi je zelo pomagala, da sem se bolje seznanil s programsko opremo CAM-CAD, ergonomijo, anatomijo človekovega zdravja ter varnostjo pri delu in varovanjem okolja. To temo sem izbral, ker ima podjetje montažni in proizvodni oddelek. V obeh oddelkih se večina dela opravlja v stoječem položaju. Po podatkih medicinske znanosti dolgotrajno stoječe stanje povzroča vnetje žil in povzroča začasno blokado sklepov v hrbtenici, kolkih, kolenih in stopalih. To izboljša bolečine v mišicah, težave z bolečinami v spodnjem delu hrbta in drugo nelagodje pri zaposlenih, kar vpliva na produktivnost in dobro počutje te osebe. Potencialne težave so torej manjša proizvodnja, več časa za doseganje ciljev in več bolniških odsotnosti. Zmanjšana produktivnost delavcev tako vodi v zmanjšanje proizvodnje in dodatne stroške ter ogroža ugled podjetja.

Uvedba tega ergonomskega stola jim bo pomagala pri lažjem delu, zmanjšala število bolniških odsotnosti in zmanjšala omejitve zmogljivosti. Stol se pritrdi na noge delavcev in oseba se lahko z njim prosto premika in sedi na njem ter dela z lahkoto. Prav tako pomaga povečati produktivnost delavca in zagotavlja neutrudno delovno vzdušje. S tem bomo nadomestili običajen stol in tako zagotovili boljše upravljanje s prostorom. Poleg tega ga lahko uporabimo tudi tam, kamor običajni stoli ne morejo priti.

To je teoretično diplomsko delo z opisno metodo dela. Uporabljen je bil sistematičen pristop iskanja literature. Podrobno je razložena ergonomija in njene veje, razložene pa so tudi prednosti in prihodnje možnosti eksoskeletov. Opravljen je bil opisni pregled, da bi odkrili povečanje produktivnosti in delavčeve delazmožnosti v povezavi z ergonomijo. V tem poglavju je opisana metodologija, uporabljena za iskanje literature.

Pridobljeni rezultati raziskave naj bi povečali produktivnost in delavnost delavca. Pričakuje se 20- 25-odstotno povečanje delavčeve delazmožnosti ter 50-odstotno zmanjšanje fizične in psihične utrujenosti delavca. Ta raziskava omogoča tudi vpogled v prihodnje področje uporabe mehatronskega eksoskeleta in protetike, ki jo upravljajo možgani.

Ključne besede: *ergonomija, eksoskelet, možgansko vodena protetika, mehatronika*

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1. INTRODUCTION

This chapter gives the complete introduction of the company background and the thesis background. It also explains the objective, expected output and used research methods and the structure of the thesis.

1. 1 Company background

BNM Automobile Industry is an automobile parts production company located in Maribor, Slovenia. The company was established in July 2011 by Gorazd Brečko and Harald Neff. The company is a pioneer in the forming of sheet metals and suitable processing thereafter. At first the company mainly focused on the production of individual segments and after getting the proper knowledge and experience the company upgraded itself to the modern methods of production, management and operations. The company's devotion, transparent policies and the hard work made it possible to achieve a leading position in the list of the automotive industry. Nowadays, the automotive industry is facing continuous and quick technological development that puts the business under constant pressure to produce high quality products with competitive prices than those on the market and consistent among the rivals. The firm focuses on sheet metal forming and further stamping the metal at a competitive cost to a required product quality.

Fig 1 BNM AUTOMOBILE INDUSTRY

Source: (www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d)

BNM set the objective of becoming a major partner in sheet metal forming, complicated stamping, assembling the formed parts to finished products, and welding for automobile and other sectors. In the automotive market, the demand of customers evolves and shifts at a rapid rate, leading to the need for a high amount of flexibility to serve and satisfy the customer needs and demands. The effort that the company is undertaking to satisfy their customers and treat their customers is said to be pretty much appreciable.
There are different stages of work done in the company. In BNM there are mainly three sections of work. Sheet metal cutting section, sheet metal forming section, and the assembly section. In the sheet metal cutting section, the sheet metal cutting process is done with the help of 2D and 3D laser cutting machines.
In the sheet metal forming section, the sheet metal is formed to the required structure by the press machines. There are 3 types of press machine.

Press Machines

In the sheet metal forming section, the sheet metal is formed to the required structure by the press machines. There are 3 types of press machine.

- The heavy presses produce a pressure of 5000-16000 kN with a table size of 3500×2500 mm.

Fig 2 Heavy Press station for sheet metal forming

Source: (www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d)

- The second line presses produce pressure between 1000-10000 kN with table size of 1400×1500 mm.

Source: (www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d)

- The last one are the light presses with 350-1600 kN pressing pressure and 100×700 mm table size.

Source: (www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d)

Assembly

In the assembly section the formed sheet metal is welded together to make the finished products. The welding is done by resistance spot welding and MAG welding. And there are two types of resistance spot welding machines

- Hanging spot welding gun machines with the power of 40-180 kW

Source: (www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d)

- Stable or T-type spot welding machines with power of 60-200kW

Source: www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d

B.N. M’s product portfolio contains the following mention:

- Raw Cabins – Unimog
- Big sheet metal parts for Zetros
- Komplete doors for Unimog and Zetros – raw
- Body-in-white parts G-Klasse
- Mudguards for BMW F12/F13
- Mini Paceman + Countryman
- Welding components of air suspension for Trucks and Buses
- Axis components for Rail Industry
- Housing for Industrialists
- Housing for Submarine

(B.N.M product portfolio, 2014)

The Customers of B.N.M are given below:

- Nagold GMBH Wagon Automotive
- Frauenthal Automotive
- Magna heavy stamping
- Wabco
- Unior
- Mahle Industry
- Meko
- Starkom

- RM Radkersburger Metallwarenfabrik
- Hengst Automotive
- EPC

(B.N.M product portfolio, 2014)

Source: (www.techpilot.de/servlets/DownloadConnector?companydocumentID=28191&lngCode=d)

1.2 PROJECT BACKGROUND

From the introduction and the pictures mentioned above shows that most of the work in the company is done in a standing position. Especially the people who are working in the middle and light presses and the workers in the assembly are using standing upright positions during the work. Even if there are two breaks in between the shifts, this does not bring any difference in the muscle fatigue and stress level of the worker.

Standing up is beneficial to your health for some time, but only if you have not been pressured to do it for hours. Excessive sitting is often risky as the metabolic rate of the body is severely affected, resulting in the risk of diseases such as high blood pressure, diabetes, obesity, depression etc. In workstations, the primary concern is to improve productivity, but the effect of labor fatigue on the worker 's body is given very less concern. Although the workplace is ergonomically designed, they are, in fact, unsuccessful in relieving worker fatigue as they almost all of the time have to work in a specific posture for hours. Up to now, in the age of increasingly increasing technology, workstations do not have a tool that can provide worker comfort. It is clear that the sloping or kneeling chair preserves lordosis and vertebral slope in both upright and slumped posture than a flat one; it results in less muscle pressure and in effect decreases back pain.

From the scientific studies and medical research experiments, prolonged standing and working in this particular posture for a regular basis will increase the chance of sore feet, swelling of legs and varicose veins, general muscle fatigue, lower back pain and stiffness in the neck and shoulders. Even though the company's working atmosphere and the working conditions are pretty much safer and healthier, but from my point of view I would like to improve the working conditions of the company by introducing the ergonomic chairless chair.
The ergonomic chair less chair or wearable chairless chair is a sitting support which is worn by the user. This consists of 2 identical leg support or the chair which is strapped to each leg of the user. Then the bottom part of the chair is attached to the holder which is connected to the shoes. This is worn by the user where they can walk while they are working and they can also sit by simply bending your knees and the chair will bend and lock itself at a certain angle, thus they can sit and rest on their thigh and gluteus muscles. This chair helps to ease the mood of the workers and decrease the fatigue in the lower back and legs. This increases the productivity of the worker and decreases sick days, especially for older workers. As we all know that when we get older, more is a chance to have health issues. So, this exoskeleton really is extremely helpful to older workers at the company.
In order to maintain a proper and healthy working atmosphere, I need to make the design and model of the chair less chair. So, I used the Computer Aided Design software to design the chair. I used Solidworks 2018 to design it.

1.3 OBJECTIVE

BNM Automobile Industry is a leading manufacturing and production company in Slovenia. So, under the constant market competition, pressure and customer demands and requirements, the company strives to increase productivity and improve both the quality and quantity of the products. In order to achieve this, workers must be more energetic, which makes them more productive.

After studying the working procedure and the production planning of the company, I came to know that they have a target for each part in one hour. They have set a time for production for each product. For some products it is 60 parts in one hour, and for some its 100 parts in one hour. So it differs from parts by parts. I have worked on all these press machines and on the assembly line. From my observation I found that, while working in a standing position for a long time, I felt tired and always tended to take a small break for 6-10 minutes every one hour. I saw the same case in other workers too, but in a sitting position it helped me to increase the production in the light press machines and assembly line, especially in the stable spot weld machine. This helped me to produce more parts in one hour. And made me feel more productive and did not have any muscular fatigue and mental stress.

By implementing the exoskeleton, the chair-less chair will increase the workability and productivity of the worker. In addition to this, the chair will also reduce the number of sick days taken by workers due to back pain and fatigue. The report describes the methodologies used to understand and design and introduce the exoskeleton chair-less chair.

So, the hypotheses are,

1. Reduces the chance of frequent intervals taken by the worker due to muscular fatigue
2. Increases the production
3. Space management by replacing the normal chair.
4. Mental satisfaction and stressless working atmosphere.
5. Less sick leave due to musculoskeletal issues
6. Consistency in daily production target

1.4 USED RESEARCH METHODS

A proper and thorough research is done for the purpose of this diploma thesis. They are primary research sources and secondary research sources.

Primary research

Primary research approach is mainly used for research in this diploma thesis. The ideas for the primary research approach was basically from visual inspection of the working procedures and working atmosphere directly. The first source of information is from workers who have done the job earlier than me and from the planning department. So their ideas will also be taken as references.

Secondary Research

Secondary research will be used to get deep knowledge about the ergonomics, working atmosphere under ergonomic policies, exoskeleton, advantages and disadvantages of exoskeleton systems and CAM CAD softwares, etc. Through researching internet sources online.

2. THEORETICAL BACKGROUND AND OVERVIEW OF LITERATURE

2.1 CONTENT

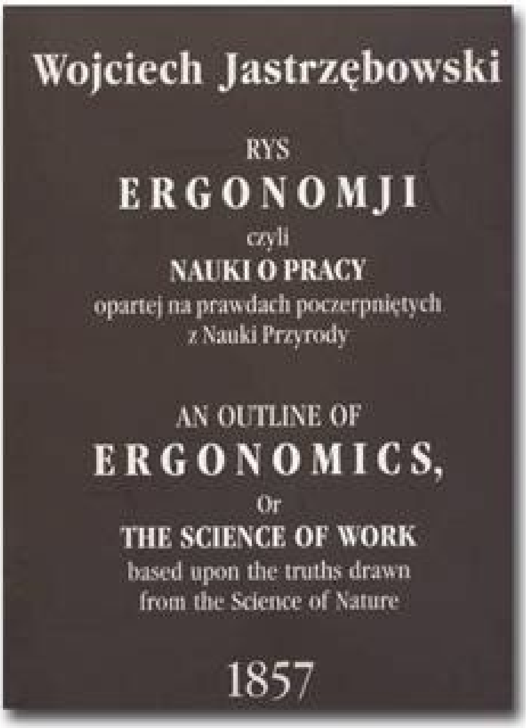
In this chapter, the research will be carried out on detailed study about Ergonomics, musculoskeletal issues due to poor working atmosphere, Exoskeleton, advantages and disadvantages of exoskeleton systems, the influence of exoskeleton and ergonomics in the automobile manufacturing industry.

2.1.1 ERGONOMICS

Ergonomics is a science of designing the workplace and job demands which fits according to the capabilities of the workers and arranging the workplace to increase efficiency and safety. Many of us will think that ergonomics is just about arranging the working environment and systematically modifying it to meet the capability of the user. For example, arranging an office room or the designing of seating and controls in the car. But ergonomics is more than this. (Bridger, 2003)

2.1.1.1 History of ergonomics

The word ergonomics comes from the Greek word "Ergon" meaning work, and “nomos" means natural law. In 1857, Polish scholar Wojciech Jarzembowski introduced this word ergonomics, and this became so popular when his Polish book was reprinted to English in 1997. The combination of the words ergon and nomos, which literally means labor and health, have also got a new meaning like "health problems caused by the working conditions". (Bridger, 2003)



Source: Bridger, R. (2003). Introduction to Ergonomics

The relationship between labor and health or health problems caused by working was pretty much noted and discussed in the ancient age of Egypt and Roman and Greek empires. It is in "De morbis artificum diatriba" a classic by Bernardino Ramazzini (1633-1714); he was an Italian physician; he stated the relationship between working atmosphere and occupational health issues. In this book, he explained about the respiratory issues like asthma and tuberculosis caused by the minute particles; they kind of problems mainly target the people who are working in both open and closed enclosures and people who deal with powder, chemicals, gas and other fine particles. He also explained about the effect of inconvenient working posture on the workers' bodies. It is said that in the 18th century Industrial Revolution helped to bring about the clarification of the relationship between labor and health issues. (Bridger, 2003)

But it took around almost 2 centuries for the development of preventive measures based on the ergonomic view and ergonomic methods and approaches. These include the measurement of occupational fatigue and the establishment of principles in the scientific management of labour. (Bridger, 2003)

In 1919, a Polish scientist Josefa Joteyko published " The Science of Labour and its organization". In this book, he briefly explained the measurement of occupational fatigue and its principles in scientific management of labour. (Bridger, 2003)

2.1.1.2. Ergonomics Explained

Ergonomics is the study of the interaction of human beings with objects. It is mainly applied to create an environment according to the physical needs of the user. It is the study of relations between employees and machines. It also concentrates on the factors that affect his relationship. Its main motive is to increase the ability of the system by upgrading the worker-machine relationship or interaction. (Bridger, 2003)

The basic principle for getting it done is introducing new designs by making better interfaces in the working atmosphere or eliminating the factors that can downgrade Employee-Machine relations.

System can be upgraded by:

1. Designing the user-interface: - This means improving the compatibility between the user and his/her task. This will help the user to be more stressless and resistant to normal errors that people are known to make.
2. Designing the working atmosphere to make it more suitable for the task.
3. Transforming the job according to the user-attributes in order to attain better compatibility between both user and the task.
4. Organizing the way of working to fit in with people's psychological and social needs.

(Bridger, 2003)

For example, in an information processing job, we must transform the interface to decrease the workload on the user's memory. Like saving or moving the information to the computer and redesign the data for easy access or recall. Likewise, in a physical task, for example, a manual handling job, we might introduce a handle for lifting the weight, or reduce the whole weight into a small portion, thus not letting the musculoskeletal system under pressure. The working atmosphere can be enhanced by eliminating vibration and noise. At the same time, improving it by introducing better seating, desking, air supply, and lighting. Work organizations or the company must monitor each and every worker and let them do their duty at their own pace. This will help to improve the overall mental satisfaction of the workers and reduce their psychological stress of being "strapped to the machine". (Bridger, 2003)

The application of ergonomics in the design of a system can make the system perform better by executing certain features of the organization functioning unpleasant, uncontrolled or unaccountable; and some of those features are as follows,

- Inefficiency: - when the effort of the worker cannot produce a decent rate of output
- Muscular Fatigue: - it happens in poorly designed tasks where people get tired pretty much easily and unnecessarily
- Excess User strain: - This means, including more combinations of subtasks which are inappropriate, and this may lead to both physical and mental difficulties.
- Accidents, errors, and injuries: - as mentioned above; this happens when both mental and physical strain increases and poor design of the interface. When the subtask increases workload will also increase and this leads to physical strain. When physical strain increases so does mental stress. When mental strain increases, concentration decreases, and this leads to a higher chance of having more errors, accidents accompanied by injuries. (Bridger, 2003)

In ergonomics, lack of attendance, physical injury, bad quality and impermissibly high levels of human errors are considered system problems rather than human problems, so this can be treated well with redesigning the working atmosphere or the working system. (Bridger, 2003)

2.1.1.3 Focus of ergonomics

Ergonomics mainly focuses on the relationship between humans and machines and the design of the interface between them. For example, whenever we use any machine or any tool, every time we deal with them through certain types of interfaces, such as, while driving a car, the steering wheel, pedals and the gear lever, when using a computer- the mouse, keyboard, etc, are interfaces. And the design of these interfaces determines how much the safety and easier it is to that machine or tool. (Bridger, 2003)

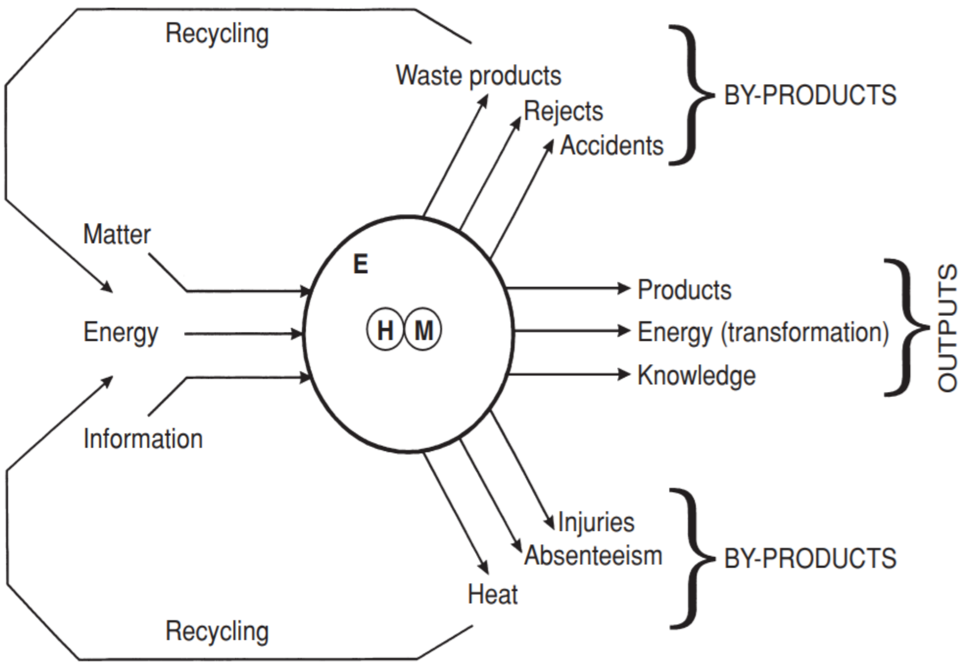


Fig 9: A simple work system

Source: Bridger, R. (2003). Introduction to Ergonomics

- **Human-machine systems**

A system comprises a set of components, the relation between these components and the surroundings around it. Most of the system comprises human effort and machines and a particular activity or function to generate some form of output. The forms in which inputs are received are energy, matter, and information. In Ergonomics, human effort or workers are part of the system, so it must be completely joined into it at the design stage itself. So, human requirements are therefore system requirements and prioritized as primary requirements. These requirements can be stated in general terms such as,

- Apparatus that are in good condition to use and safe.
- Tasks that are suitable for people's physical and mental limitations, expectations and the level of their training.
- A comfortable working atmosphere which is suitable for the task.
- Job management approach of addressing the social and economic needs of the people. (Bridger, 2003)

- **Compatibility - matching demands with capabilities**

Compatibility between user and system can be gained at a certain number of levels. Basically, compatibility can be encountered through these levels; they are biomechanical, anatomical, behavioral, physiological and cognitive levels. These are the basic strategies commonly used in the application of ergonomics across a wide variety of directions and regulations. Here comes the balancing act; in order to gain compatibility, we need to weigh user capabilities against the demands placed by both environmental and technological limitations. (Bridger, 2003)

There are cases when compatibility cannot be achieved, this incompatibility occurs due to a variety of reasons; for example:

1. Not considering the human requirement which is required for the best functioning of the system at the design stage.
2. unprofessional design of task. For example, the unexpected introduction of a new machine or a device can bring changes in the way tasks are done before and can bring incompatibility with user expertise, habits and routines.
3. Absence of trial-run or prototyping: Present- day computer program improvement is effective since it is profoundly iterative. Users are counseled or given better training and detailed explanations from the conceptual arrangement right through to pre-production prototypes. (Bridger, 2003)

Table 1 Basic interactions in a work system and their evaluation

Interaction	Assessment
H > M The basic control behaviour carried out on the machine by the person. Application of massive forces, "fine tuning" of controls, storage of raw goods, maintenance, etc	Anatomical: posture and movement of the body and limbs, size of forces, cycle time and movement frequency, muscle exhaustion. Physiological: work rate (consumption of oxygen, heart rate), labor force fitness, A physiological tiredness. Psychological: capacity specifications, stress levels, parallel / sequential data processing, consistency of the modalities of practice.
H > E: The human impact on the natural climate. People emit heat, noise, carbon dioxide, and so forth	Physical: Aiming to measure the working environment. Implications for Quality enforcement.
M > H: input, and knowledge show. Machines can use vibration, acceleration, etc. to exert forces on humans. Machine surfaces can be exceedingly hot or cold and endanger human health.	Anatomical: Controls and device construction. Physical: Target vibration calculation, controlled machine reaction forces, noise and surface temperatures within the workspace. Physiological: should interactive relationships exceed limits? Psychological: application of concepts of categorizing to model faceplates, panels and graphic displays. Loading information. It is consistent with user expectations.
M > E: The device can change the working environment by generating noise, heat, toxic gases.	Mostly by industrial engineers and hygienists
E > H: In addition, the environment can affect the ability of the human to connect with the machine or remain part of the work system (because of smoking, noise, heat, etc.)	Physical / physiological: assessments of noise, lighting and temperature of the system
E > M: System operation may be influenced by the environment. For example, it can cause components to overheat or freeze. Most devices work with oxygen. Oxygen is generally considered to be free and unrestricted, rather than part of the fuel.	Industrial / site engineers, maintenance staff, managers of the infrastructure etc.

Source: Bridger, R. (2003). *Introduction to Ergonomics*

- **A basic work system**

Even in an amazingly simple system where there is only 1 worker, 1 machine and an environment, the possibility of interactions are 6 directional. They are H>M, H>E M>H, M>E, E>H, E>M (where H-Human, M-Machine and E - Environment) within the six, four of them show human involvement. Each element of a specific work system has a relation between the others directly or indirectly.

For Example, when we install a new machine which is not familiar to the working environment and user. So, it leads to a condition like change in the state of the environment. This includes the emission of heat and noise; this may affect the user.

All work systems have around them a physiological or biological boundary, which distinguishes them from neighbouring structures. Systems analysis is the name of the discipline that discusses work systems' form and composition and offers the means by which simple systems can be combined to build more complex systems. The examination of the structures is an important part of every advanced ergonomic function (Bridger, 2003)

2.1.1.4 Application of Ergonomics

The goal of ergonomics is to improve the functioning of a work system by improving the interactions between people and machines. Better functioning can be more precisely defined, for example, as more performance from fewer system inputs (greater 'productivity') or increased reliability and efficiency (a lower likelihood of improper system component interactions). The exact definition of improved performance depends on the context. Whatever definition is used, it should be that the whole working system is not just one of the scales and components. Improved machine performance which increases mental or physical stress on workers or damages the local environment does not improve the overall performance of the work system or its goals as well. Redesigning workstations to make workers more 'comfortable' is an incorrect excuse for implementing ergonomics if performed superficially, for their own sake, and not to improve any aspect of the overall work environment, such as decreased absenteeism and less injuries due to improved working conditions. (Bridger, 2003)

In reality, ergonomics influences the design of structures in two ways.

1. Many ergonomists work in research organizations or universities and conduct fundamental research in order to discover the aspects of individuals to be included in design. This work also contributes to the drafting of requirements, regulations and design recommendations, whether directly or indirectly.
2. Second, many ergonomists operate either personally or in an organization, in a consulting capacity. They work within the framework of a design team and contribute their expertise to the design of interactions between person and device in the work systems. This often involves applying guidelines and expertise of the standards to specify system-specific characteristics. Specific structures of function are hierarchical. This means that the main role consists of sub-tasks and is controlled by higher-level constraints, which manifest as supervisory style, form of organization of work, working hours, and shift work etc. For reality, if we try to improve a mission, we rarely reshape the job itself. (Bridger, 2003)

2.1.1.5 Human – machine systems overview

- Human Components

The human body is part of the physical world, obeying the same physical rules as all things, both animate, and inanimate. At this stage, the aim of ergonomics is to maximize the relationship between the body and its physical environment. This means ensuring that physical area requirements are fulfilled and that the internal and external forces that work on the body are not harmful. Ergonomic issues also occur because, while the operator may perform the job, the effort needed overloads the body's supporting and sustaining functions and triggers fatigue, injury or error. (Bridger, 2003)

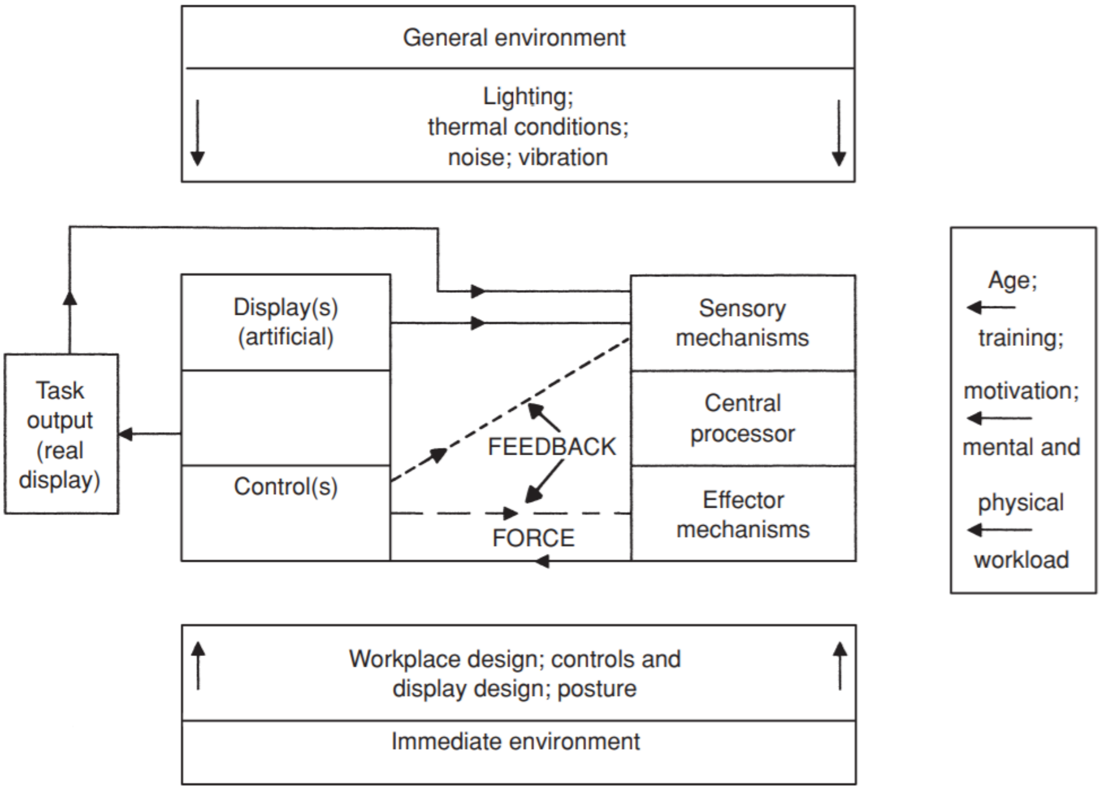


Fig 10 Human–machine model

Source:
https://books.google.si/books?hl=en&lr=&id=Jr4FIRQnVqQC&oi=fnd&pg=PP1&dq=introduction+to+ergonomics&ots=QoFhcfy51Z&sig=fBF0zSYDSGbSo3s8dqUsUoReIW4&redir_esc=y#v=onepage&q=introduction%20to%20ergonomics&f=false

2.1.1.6 Modern ergonomics

Modern ergonomics refers to the design and assessment of products and work processes. Unlike in previous eras when an engineer designed an entire system or product, design nowadays is a group effort. Typically, the ergonomist has a significant role to play in both the creative and comprehensive design phases as well as in developing and testing the current products and services. Modern ergonomics applies to the design of the job environment in many respects. These operations should be viewed as an integral part of system organization and development rather than as 'optional extras' (Bridger, 2003)

These aspects are as follows:

Table 2 Donation of modern ergonomics in designing and operating processes

	Modern ergonomics role in contributing in systems organization and development
1	Basic format for human – machine systems explanation
2	Classification, evaluation and management of human-related interface problems
3	Study of jobs and human – machine interactions
4	Assessment of socio - technical impacts of design alternatives
5	Creation of new ideas for human – machine system structural analysis
6	Identify key elements of human and biological science and their consequences for the design and management of systems

Source: Bridger, R. (2003). *Introduction to Ergonomics*

1.1.2 AUTOMOBILE MANUFACTURING INDUSTRY

The automobile industry is a wide range of different companies and organizations associated with automotive design, development, manufacturing, marketing, and selling. This is one of the world's most important economic sectors by sales. Today, the major car manufacturers have a manufacturing plant in the various markets, and a car is manufactured for that market as well as for exports to other markets from each platform. Major players in the automotive sector have not only one big factory but ship its goods to all other nations. The global automotive industry today is concerned with customer needs for styling, security, and pleasure, and with labor standards and productivity in manufacturing. The sector is at the crossroads of multinational mergers and production center restructurings to new industrialized countries. They are different, as consumers ' expectations vary from country to country. In South America, for example, the income is lower than in Western Europe, and buyers need more reliable cars. The buyers in the USA want more room in the vehicle, so that is a significant aspect for a vehicle to succeed there. (Rae)

While steam-powered road automobiles were built earlier, the automobile industry's roots are based in the invention of the gasoline engine in the 1860s and 70's, primarily in France and Germany. At the turn of the 20th century, British, Italian, and American makers had followed German and French factories. Mass production was an American innovation. Although Europe had shared in the experimentation, the American role was emphasized in the popular description of standardization and interchangeability as “the American system of manufacture”. The fundamental techniques were known, but they had not previously been applied to the manufacture of a mechanism as complex as a motor vehicle. (Rae)

1.1.2.1 Ergonomics and automobile industry

Automotive manufacturing industries are one of the major fields in which ergonomic mandates are followed and provided to their workers. Many of them use existing laws such as OSHA, and with the help of this law they have also introduced their own set of guidelines and protocols. In automobile manufacturing industries, there are many types of work which require a particular type of body posture.

These are some of the examples for this:

- Bending down: - Bending down to pick up or to lift something to a certain height. During this time, it is especially important to make sure that your back is straight and use your legs to move vertically. This will help to reduce stress in the spine. The intervertebral disks function as "suspension systems or shock absorbers " and decrease the stress on the vertebrae. Their task is a significant one during weightlifting activities: to balance the lower back. Bad posture, overly heavy lifting weights may cause one or more intervertebral disks to "slip" or "disk herniation."
- Body Twisting: - twisting the body while carrying something heavy. This may also cause injury to the spine.
- Push and pull occur during the transportation of heavy equipment using carts or trolleys. When doing such work, make sure that you are not overexerting your back, because this may cause serious injuries to the lower back vertebrae of the backbone. In-order to eliminate these types of mistakes, the casters can be used to prevent excessive push and pull force, thus reducing overexertion.
- Reaching to work overhead: - Work which is done by reaching overhead like lifting boxes or tightening a nut can be extremely dangerous. In some cases, mistakes may result in death. To avoid this type of issue shelves and racks should be placed only at a particular height where it can easily be accessible to the user. Material dropping is a big problem for every place of operation. Vision disability, stumbling, technical malfunction or negligence of the worker may all contribute to severe injury or death. For example, if materials are not properly packed, the load will slip and fall on workers nearby. These kinds of tasks in the automobile industry can cause serious injury to the worker if not done correctly. (Malek, August 8th, 2016)

1.1.3 Health issues and prolonge4d standing

A physically active lifestyle has long been known to be beneficial in better health and well-being, as well as reducing the risk of developing chronic diseases. Today, many companies recognize that successful market success requires continuous improvement in a number of key areas, including efficiency, quality, workplace safety and health; protection of the natural environment, and the costs of goods and services. In addition to technological advances and the growing complexity of goods and procedures, many companies face rising prices, the resistance of consumers to price rises, or increased demands for well-being and health for employees. Such circumstances pose management with tremendous challenges. Consequently, the focus on continuous improvements in efficiency, ergonomics and work health and safety has received significant attention in the literature. (Dzissah, 2005)

Anyone working on a manufacturing plant's production side would admit that handling and managing as regards workplace health and safety is one of the most demanding conditions.

Workers also can experience a wide variety of physical and chemical threats even with sufficient health training and adherence to procedures. The manufacturing sector is also complex, and as a result of the nature of work being done, different sub-sectors face different problems. Loud noises, falls, and fractures are common issues for workers when industrial product manufacturing requires the operation of robotic systems, hydraulic systems, conveyors, punches, presses, and other large-scale manufacturing equipment. Equipment can cause any number of soft tissue injuries, particularly when it is worn-out and lacks safety features (e.g., insufficient protection and faulty security mechanisms such as emergency stoppages). As workers participate in lifting and prolonged standing, musculoskeletal disorders (upper limb disorders) and low back pain are frequently identified. Respiratory diseases and asthma arise when there is a worker 's ability to inhale flavourings (food production) or where fine dust is emitted into the air (e.g. wood and furniture production). Allergy-inducing colorants cause a disease known as contact dermatitis (skin rashes), and the colouring is associated with fabric and clothing (textiles) handling. Infections caused by animals grow at works that handle food (e.g. meat and poultry). Strain and mental pressure occurred at rising levels across manufacturing subsectors. Psychological and social issues can occur when organizations adopt a culture within the organization that demands a higher pace of work, a hectic schedule, and less rest time during the working day. Over the last 10–15 years, the structure of the workforce has changed rapidly. There has been a shift in the automotive industry, as in other market sectors, towards collaboration, downsizing, and embracing flatter management structures and flexible production. In addition to regular, full-time jobs, several new employment relationships include contractual and part-time work. The workforce has also shifted, with more women, refugees, and younger workers making up the demographics of the workforce. These issues have only been explored recently, but recognizing their impact is critical to creating safe and successful workplaces. (Thomas R. Waters, 2015)

All standing and treadmill desks showed the promise of a daily usage capacity to boost health outcomes. Using a treadmill desk, however, has usually resulted in greater physiological changes than using a standing desk. It may be the product of treadmill desk interventions that appear to be longer than standing desk interventions. Nonetheless, despite the increased treadmill walking effort compared to standing, more physiological change can be expected with the use of treadmill desks. Implementing ergonomic techniques such as changing the condition of the floor, using anti-exhaustion mats, and wearing shoes with insoles are still inconclusive in reducing the risk of muscle soreness among human operators. This review, therefore, encourages more in-depth research into the quantification of the efficacy of such proposed ergonomics measures in a real-world application, such as in industry. (Thomas R. Waters, 2015)

1.1.3.1 Musculoskeletal issues

In developed and industrial developing countries, musculoskeletal disorders (MSD) are one of the main causes of workplace injury and disability. Automotive assembly is one of the major industries in some countries and because of the nature of the activities, employees in this specific industry are subjected to different working conditions that may contribute to MSD. Ghasemkhan et al have reported a high possibility of MSD among employees on the automotive assembly line. Hußain, T. 2004 Study conducted among truck assembly employees and found that up to 79 percent of employees had MSD. Lynn and E Mcanany. Nigel Corlett (1993) tabled a draft and the process became known as RULA. RULA is designed to evaluate operators who are vulnerable to musculoskeletal loading. The Ovako Working Posture Analysis Method (OWAS) is an ergonomic evaluation tool used for estimating MSD risk. OWAS is a posture-based methodology that is used to assess job-task demands and classifies workers into risk categories known as "Action Categories" 1 – 4 ranging from 1, meaning no elevated risk to 4, meaning significant harm is probable. Schaub notes that the screening method for the European Assembly Worksheet (EAWS) allows for a perspective assessment of individual workstations in terms of their ergonomic design efficiency. This review can also be used as an objective and practical way to estimate physical workloads for automotive assembly operations. (Chakravarthy)

You can categorize the key risk factors for musculoskeletal disorders under one of four themes:

- Force
- Posture
- Repetition
- Duration of task

Tasks involving the adoption or repetition of postures at the extreme of the range of repeated movements can lead to imbalances in antagonistic muscle-tendon units, leading to the deterioration of joint function. The complex dimensions of task success are of concern in relation to the prevalence of musculoskeletal disorders, in addition to tissue strength and training. Marras and Schoenmarklin studied the wrist movements of staff working in occupations that included a lower or higher chance of carpal tunnel syndrome. Also reported were the angular velocity and wrist accelerations when traveling inside the corresponding spatial planes. No major differences in wrist posture were found between the high- and low-risk classes. The authors interpreted the results according to Newton's second law of motion. In order to produce greater wrist accelerations, greater muscle forces are needed which are transmitted through the tendons to the bones. In a similar way, Marras was studying trunk movement in a variety of jobs in relation to the possibility of low back disorder. Moreover, lateral trunk velocity and twisting trunk velocity were also correlated with high-risk jobs the quicker these moves were, the greater the risk of injury. In order to stabilize the joints involved, greater coactivation of synergistic and antagonistic muscles is required when a part of the body has to be moved rapidly, in a regulated way. When several of the muscles involved function against each other, the result is an amplification of the loading of the joint. A general theory for disorder prevention would tend to be reducing the rate of repetition and not just the amount of repetitions or work periods in a job. One method to do so is to integrate mission micro-elements into bigger units. Further information can be found on tissue behavioural responses to mechanical loading causing serious injury. Any factors which reduce the strength of parts of the body will increase the risk of injury. However, the injury threshold varies depending on the level of exhaustion during the day, or throughout the change in work. In a similar way, it has been hypothesized that forward-bending in the early morning is more dangerous than at other times of the day. In a group of sufferers trained to prevent early morning bending of the spine, Snook records substantial reductions in back pain. The definition of healthy workloads is constrained by the fact that no absolute injury threshold appears to be present in human tissue. Day time and shift time are important determinants on an organizational level. (Waters1, 2014)

1.1.3.2 Lower back pain

A variety of tests for low back pain (LBP) have been related to prolonged standing. By far the most calculated effect is low tiredness and pain in the back. Roelofs (2002) recorded low back discomfort with extended standing in a study of bank tellers, and Drury (2008) reported that those who stood for long periods during the day showed substantially greater body parts discomfort relative to those who sat most of the day. A variety of studies investigating possible biomechanical markers of LBP vulnerability due to prolonged standing have been performed. Researchers have indicated that the risk of LBP is increased during prolonged standing due to excessive co-activation of muscles involved in postural stability (Nelson-Wong 2008; Marshall 2011). In particular, Nelson-Wong (2008) postulated that prolonged standing results in a substantial rise in the co-activity of the gluteus Medius (GM) muscles, a muscle group that helps to stabilize the pelvis while standing by abducting, rotating medially, and rotating the thigh at the hip laterally. (Waters1, 2014)

Some studies have been performed to determine whether there is evidence of increased GM activity during prolonged standing (Nelson-Wong et al., 2008, and Marshall 2011). Using electromyography (EMG) measurements, the researchers found that participants who recorded low back pain displayed higher left and right GM co-activation compared to those who did not report LBP during the standing task. Their findings suggested that prolonged standing had impaired stamina and co-activation, and that this influenced LBP studies. (Waters1, 2014)

Nelson-Wong studies have shown additional evidence of elevated symptoms of LBP due to prolonged standing. The researchers stated that after lengthy standing activities, 40 % of participants developed LBP, decreased vertebral joint rotation stiffness in lateral bending, and improved postural stability of the excursion. During unilateral stance, the center of pressure measurements had no impact of standing on forward flexion, and males had a greater COP excursion than females on the single leg-standing test. In a related study investigating the effects of sloped surfaces and their effect on biomechanical responses to prolonged standing, it was found that standing on sloped surfaces decreased subjective reports of pain for those who experienced LBP. The remaining research concentrated on associations between prolonged standing and recorded LBP epidemiology. The hours of sustained standing for comparison may have been insufficient to cause a significant difference in health results, and the severity level of the study's measure of LBP outcome was extremely poor. (Waters1, 2014)

2.1.4. EXOSKELETON AND CHAIRLESS CHAIRS

Throughout recent years, musculoskeletal pain and risk factors have been analyzed in depth and continue to inspire innovative approaches for the identification and resolution of the problem. During the latest age of the Fourth Industrial Revolution, the emphasis was on assisting operators with activities that were difficult to automate by collaborative robots or exoskeletons. An exoskeleton can be described as a wearable, external mechanical structural system which improves the user's strength and endurance. Exoskeletons can be categorized into two types: active and passive.

2.1.4.1 Active Exoskeleton

Active exoskeletons come in the form of powered actuators (electrical, hydraulic, pneumatic, or other) to increase human capabilities. Active Exoskeleton is a human interface to capture motion and communicate with force. The device is attached to the human body at four points and can communicate with the individual in the upper leg, upper arm and forearm. The four human fixing points are associated with nine degrees of freedom through a kinematic structure. (R. P. Matthew, 2015)

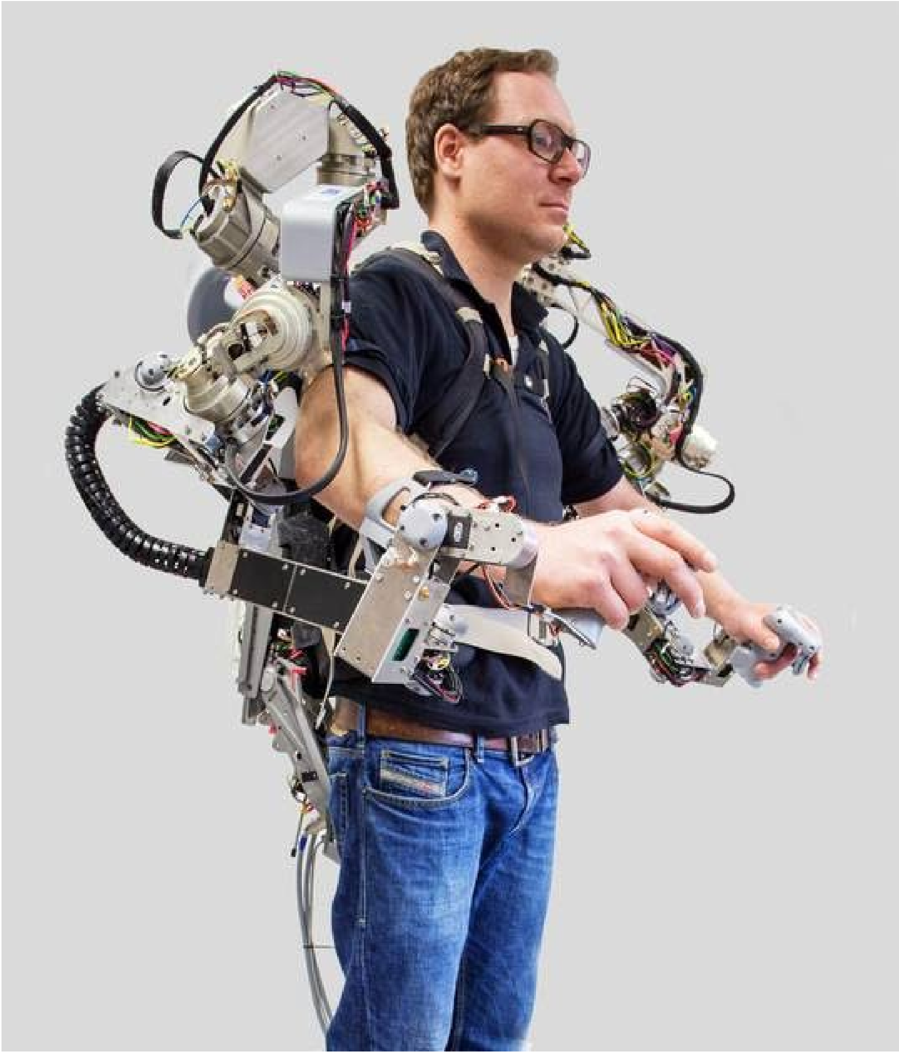


Fig 11 Active Exoskeleton

Source: https://robotik.dfki-bremen.de/en/research/robot-systems/exoskelett-aktiv-ca.html

2.1.4.2 Passive Exoskeleton

Alternatively, passive exoskeletons consist of unpowered mechanisms (using fabrics, springs or dampers) for storing energy from human motion and releasing energy when necessary to maintain a posture or motion. This exoskeleton is a wearable device which supports the human being to produce the physical power necessary for manual processes. A passive device does not use an external source of power but uses materials, springs, or dampers with the ability to store and release energy from human movements when necessary. (R. P. Matthew, 2015)

Fig 12: Passive Exoskeleton

Source: https://newatlas.com/passive-exoskeleton-transfers-pack-weight/38895/

You could also classify exoskeletons based on the field of application. They could be used in the armed forces, rehabilitation services or industrial applications. For rehabilitation purposes, most commercially, available exoskeletons were made. In terms of industrial exoskeletons, active exoskeletons are still being focused on developing, while passive exoskeletons are already on the market. Another method of classifying exoskeletons might be based on the supported part of the body: upper limbs, lower limbs, spine or a combination of body parts. (R. P. Matthew, 2015)

2.1.4.3 Chairless Chair

Chairless Chair created by Swiss start-up Noonee, it is a hydraulic powered chair that lends lower-body support to people who have to stand all day long. As the name suggests, the Chairless Chair is a wearable sitting support for standing workplaces which allows the user to move conveniently between a standing position and a sitting position. The unit locks up at a user-selected height as the user sits and maintains sitting support.
The concept is simple and clear: the back of the worker's leg is supported by a titanium frame like a flexible brace, while a support belt is wrapped around their waist. Workers can stand and walk as usual, but pressing a button locks the frame in place at the desired angle when they

choose to sit down. The body load is transferred to the floor or to the heels via the frame. (Looze, 2015/10/07)

Fig 13 Chairless Chair (a)

Source: https://www.wired.com/2015/03/exoskeleton-acts-like-wearable-chair/

It is one solution to reduce the exposure of employees to associated risks for developing work-related musculoskeletal disorders is to use exoskeletons. Using such a device in dynamic environments has the advantage over, e.g., robotics because it does not need any programming or teaching of robots. Moreover, exoskeletons are worn at the body and do not have to overcome spatial issues. In a recent review, 26 different exoskeletons have been described, of which only two were designed to support the lower body during heavy work. For lower intensive work tasks, like assembly tasks in the automobile industry, no study has focused on using exoskeletons to relieve employees while performing the work standing. (Tartaglia S. B., 2018)

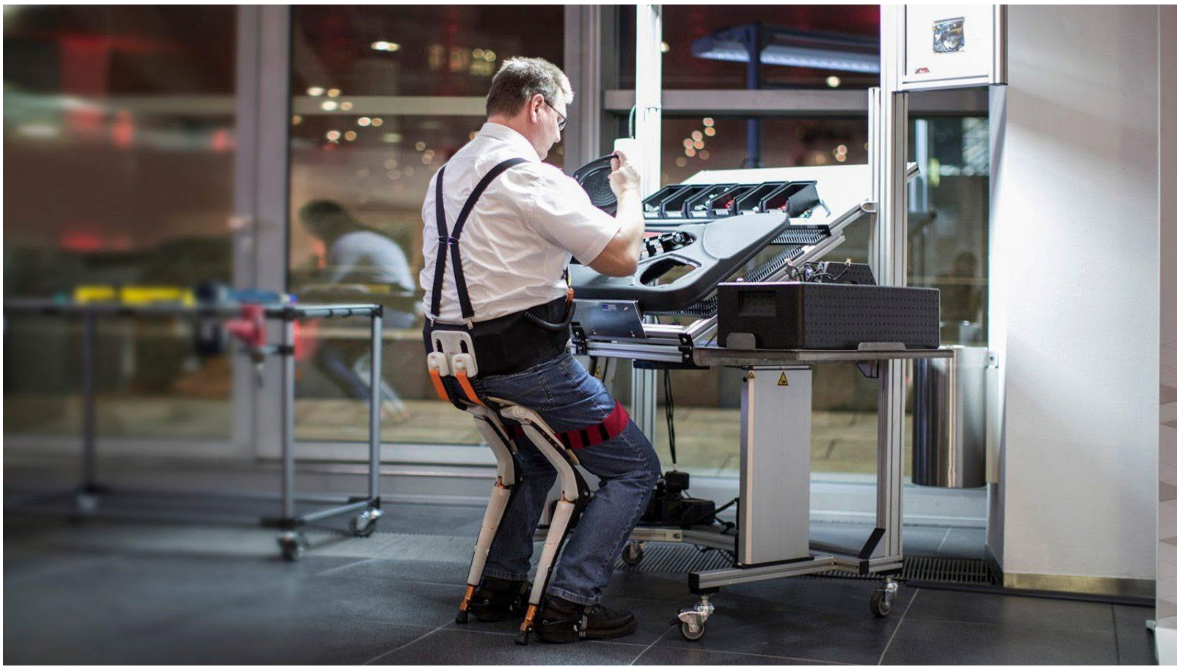


Fig 14 Chairless Chair (b)

Source: https://www.dezeen.com/2017/07/06/chairless-chair-designed-provide-support-active-factory-workers/

The chair frame can be adjusted to suit people of different heights and girths, and it can also be fitted to various work-safe footwear. It is made largely of engineering plastics like polyamide, chosen for their light weight and durability (Tartaglia S. B., 2018)

2.1.4.4 MSDs correlation

The incompatible posture associated with the job role at a height below the waist, produces a position for which the back muscles are constantly demanded. This type of situation could result in MSDs which could affect the whole body, especially muscles, tendons, ligaments, and blood circulation. Standing up induces irreversible contraction of the body and leg muscles. The muscles do a static job and tire easily if they cannot relax. Furthermore, heavy stress is exerted on the joints, ligaments, and intervertebral discs. Standing stimulates the circulation of blood more and takes more energy than sitting. However, standing for a long period of time may cause exhaustion and suffering: the tendons and muscles are in a stress state; the joint systems are cramped, raising the risk of venous stagnation in the lower extremities. At first, there is a feeling of tiredness that turns into pain: if this symptom persists over time, you will get to a real illness that will heavily affect these workers' work and social life. A group of ETH Zurich researchers have found that standing up too often can cause problems, even the other way around. Researchers have shown in a study published in the journal Human Factors that standing on their feet can cause joint and foot pain in the short term and can cause back problems and irreversible muscle damage in the long term. (Tartaglia S. B., 2018)

3 RESEARCH FINDINGS AND METHODOLOGY

This is a theoretical diploma work with a concise working method. The literature used a systematic search technique. A narrative analysis was conducted to discover the worker's improved efficiency and workability in relation to ergonomics. The methodology used for the analysis of literature is listed in this section. Research methodology, A systematic analysis of literature has been conducted in this diploma work to find scientific research that provided the basis for a review of existing knowledge. A method of analysis of narrative literature was chosen for a detailed overview of this information.

3.1 INTRODUCTION

One of the main problems is having inconsistency in daily production. The production number of some parts varies from day to day. This is because of the frequent intervals taken by the workers due to muscular fatigue which is caused by prolonged standing. Productivity is getting worse because of this. Inconsistency leads to pending work and this will increase the workload. So, when the workload increases, it will put both workers and management under pressure. It is very necessary and important to find a solution to reduce the frequent intervals taken by workers.

Analysis of the criteria is a way to figure out the key problems that a team member requires further timeto solve. This is a great approach to consider the current situation and the perspective of the team leader. This report outlines the activities carried out between September 2018 and January 2019 to advance the work package for the study of user requirements. It explains the techniques used to classify the criteria, the initial observations, and the outcomes of the full collection of user surveys analyzed.

3.2 METHODOLOGY

To fulfill this requirement and gain a clearer understanding of the expectations, a face-to-face conversation was conducted in which my co-workers helped to collaborate in the discussion to strengthen the aims and objectives. The qualitative research was carried out based on some of the questions prepared. The analytical task and interview questions involving personal feedback helped us identify the issues. The observational analysis and some work were done to find out the number of parts produced while in a sitting position and observed the number of frequent intervals taken during the working hours.

3.2.1 Result of Observation and discussion

The observation analysis and discussion took part with my colleagues who work in the Vertical T-type Spot welding machines for nut welding and sheet metal forming machines. As the working posture in the vertical T-type spot machines and the sheet metal forming machines is a standing position which increases muscle fatigue. This muscular fatigue and tiresome working posture lead to frequent ease off intervals. This affects both the quantity and quality of production. When production decreases the company will not be able to deliver the products to the customers at the promised date and time. So, it is especially important to increase production by improving the working atmosphere of the company. And when categorizing the workers in the company according to their age, around 60-70% of the workers are between the 40-50 age groups. And out of this, the majority of workers have health issues like varicose veins, swollen feet, lower back pain, and lumbar spine issues. So, the ergonomic chairless chair is a perfect solution for the workers to work in ease, where they can work in a sitting position, which will not lead to lower back pain issues and muscle cramps.

Another important reason behind implementing this ergonomic chairless chair is that it replaces the normal chair in the working space and saves more space for storage facilities or room for finished products.So, the introducing chairless chair to company can benefit both the workers and company:

- Physical strain due to work can be reduced
- can reduce the number of absent days or sick leave taken by workers due to work strain

- making the work atmosphere more friendly and comfortable
- increase the productivity and quality of the workers, thus increasing the company reputation
- helps in maintaining a good commitment with workers to the company.

3.2.2 Interview data interpretation

After the conversation and discussions with colleagues, the information revealed that standing posture at work leads to muscular fatigue. This forces them to take frequent ease off intervals. This muscular fatigue will also reduce the pace of the worker. Thus, production of the parts gets exceptionally low and inconsistent. This has caused some problems in the company with existing customers too. In order to meet the daily production target and to deliver the products at the promised time, the company was forced to work on night shifts too. This is extra labour, extra cost, and still production is not up to daily shift targets.

Fig 15: Product that undergoes nut-spot welding

Source: Own source

The picture above is one of the products of the company, where there are two nuts welded to the work piece by vertical T-type spot welding machines. The estimated production target for this part in one hour is 100, but the actual production rate of this part varies from hour to hour. There is no consistency in production.

The chart given below explains the rate of work done or the production rate in each hour.

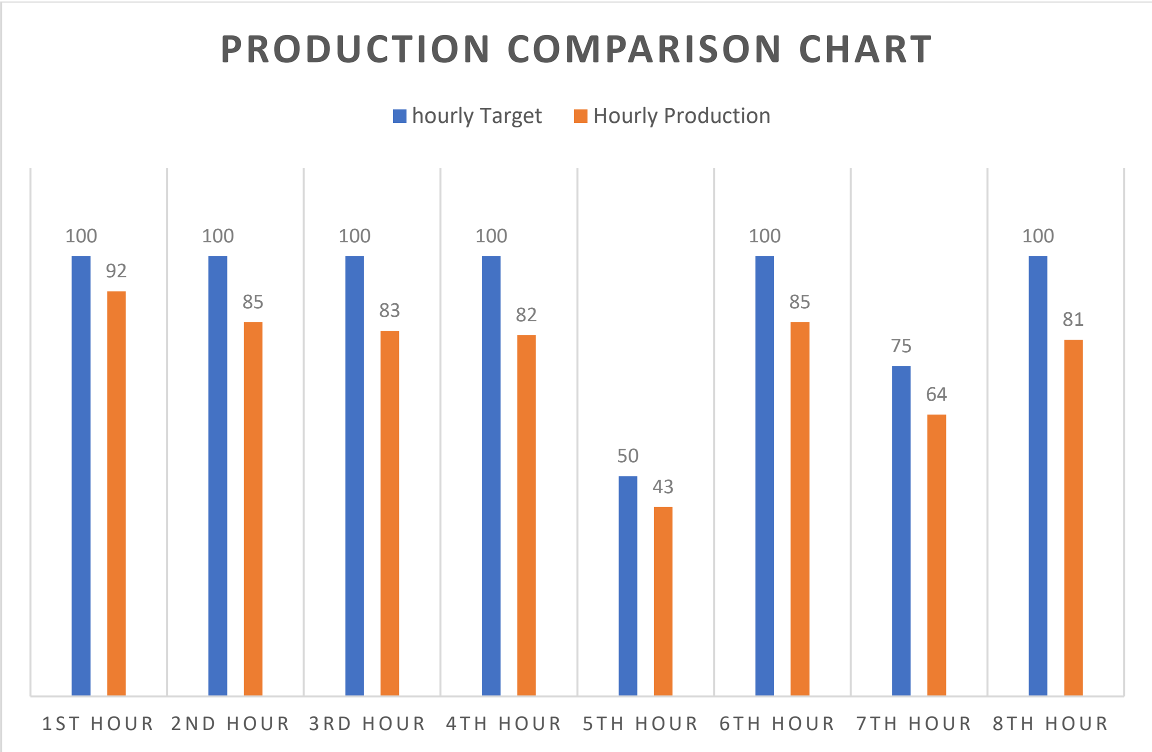


Fig 16 Production Comparison Chart

Source: Own source

The chart above shows a comparison between the required number of parts produced in one hour or the hourly target and the actual production in one hour. This explains the situation as the current working procedure is very tiresome and around 10-20% decrease in every hour production. So, changing the working posture to a sitting position can make a huge difference in production. So, implementing chairless chair exoskeletons would be a better idea than normal, as they will save space and the workers can also move freely with them.

Another important information that got out after the interview and discussion was about the extra breaks that workers used to take in between the working hours. The amount of time the workers have taken for ease off intervals are also high; the structure of the working period of the company is likewise.

There are two shifts which comprise of 8hours. The first shift starts at 6am in the morning and ends at 2pm; the second shift starts at 2pm and ends at 10pm. There are two allowed breaks in between the shifts. The first break is after the first four hours of work, and is for 30 minutes; then the second break is after the 6th hour for 15 minutes, respectively. So the average total working time in a shift is 7 hours and 15 minutes, but when it comes to reality, this total working or production time of the company varies day by day. The straight 4 hour work in the first stretch of shift has given the worker intense pain and discomfort in the standing position so that they are used to taking the break even if they don't feel any muscular fatigue but this practice will go on like a routine.

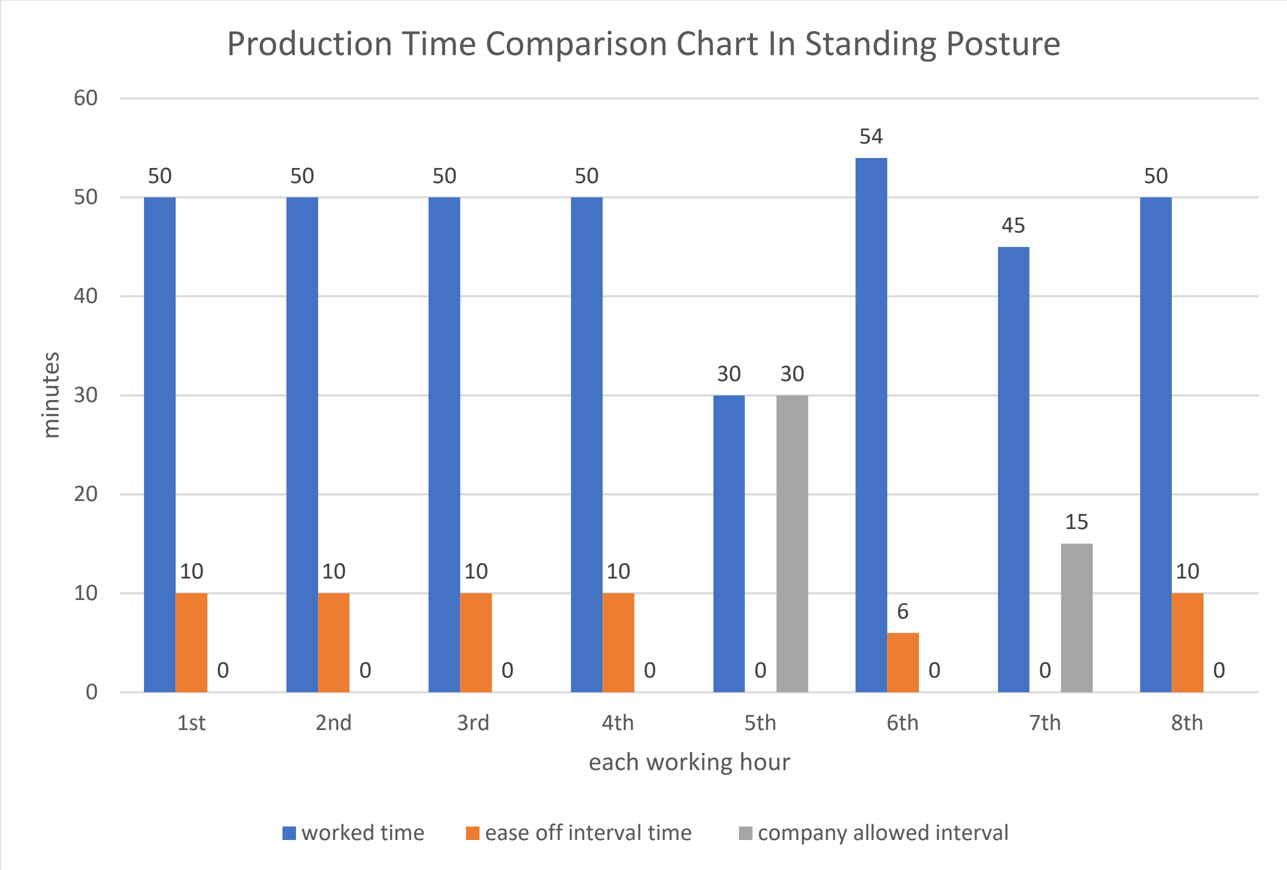


Fig 17 Production Time Comparison Chart (a)

Source – own source

The chart above describes the total amount of time the workers use for working each hour of the shift. And a total sum of almost one hour is being lost as ease-off intervals. This one hour cannot be negligibly ignored because we are losing 2 hours extra from our everyday total working time. These 2 hours per day grow into 52-54 hours in a month, which is 640-648 hours in a year, which is approximately 80 shifts; that is, 40 working days. Muscle fatigue due to prolonged standing costs 40 working days, which is approximately two working months for the company and leads to less productive employees with lower back pain, lumbar spine issues, varicose veins and other health issues.

3.3 STRATEGY AND PLAN PROPOSAL

B N M is an upcoming and developing automobile manufacturing company which produces automotive parts and assembly to leading Automobile brands such as BMW, Mercedes Benz, JJaguar etc. Behind every successful company, there are few key elements which have helped to generate and maintain success. Out of this one of the main elements is the bond between the management and the employees. When this bond gets stronger, stronger will be the company's functioning and higher will be the productivity. When productivity increases, it is possible to make a good impression among the customers by delivering their products in the promised time. This leads to raising the goodwill and reputation of the company.

As the working culture of the company is explained, currently, the main problem in the company is mainly related to low production and inconsistency in daily production margin. Even though the company manages to cope with the customer needs and deliver the finished products at the promised time, that is done by adding an extra shift, which is extra labor and extra cost. So the company requires a proper solution to this problem.

While working in all the sections of the company, a detailed analysis of the work culture of the company and verbal discussion and conversation with the employees helped to get a proper outline about the reasons behind the low productivity and daily production target inconsistency. Therefore, the company required a solution to increase production to a standard level.

One of the main reasons behind the problem is the musculoskeletal issues; the working conditions were prolonged standing, causes muscular fatigue and the people are forced to take ease off intervals and some of them used to take sick leave too. So, while working in the T-type spot welding machines, where working posture in standing position and the same problems are also noticed. So a suggestion was put forward of changing the working position to sitting by adding a chair. This really helped to solve the problem to a further extent, but a new problem occurred that by the introduction of the chair led to the increased use of the space in the working atmosphere. So, this can be eliminated by the introduction of ergonomic chairless chair exoskeletons.

The project mainly focuses on increasing productivity by modifying the working posture to sitting position with the help of the exoskeleton chairless chair and the designing 3d modelling of the exoskeleton.

4. DESIGN OF EXOSKELETON CHAIRLESS CHAIR

Design is the primary part of the exoskeleton; we cannot create a chairless chair with precision without design. There is a lot of software to design the device, but for modelling, I used Solidworks 2019. In order to make the exoskeleton first, we need to do the mathematical calculations for understanding the capability of the exoskeleton and how much force this exoskeleton can hold on a particular dimension and for the material assigned. I also did simulations to understand the stress, strain, and displacement that happen while the force is applied to the exoskeleton. The exoskeleton is an assembly which consists of 3 different parts or components. The attributes of each component, like the material used for the part and the measurement or dimensions of the part, are also explained and its function is briefly depicted with the help of the 3D model.

4.1 Components Details

- Under thigh support
- Calf support
- Damper

4.1.1 Under thigh support

This is the part that comes under the thigh and it acts as the seat where the user can sit. There are 4 hooks or spaces provided on the seating surface to attach the strap which is strapped to the thigh, so that it will attach to the user body. The material assigned for this part is Ductile Iron (SN).

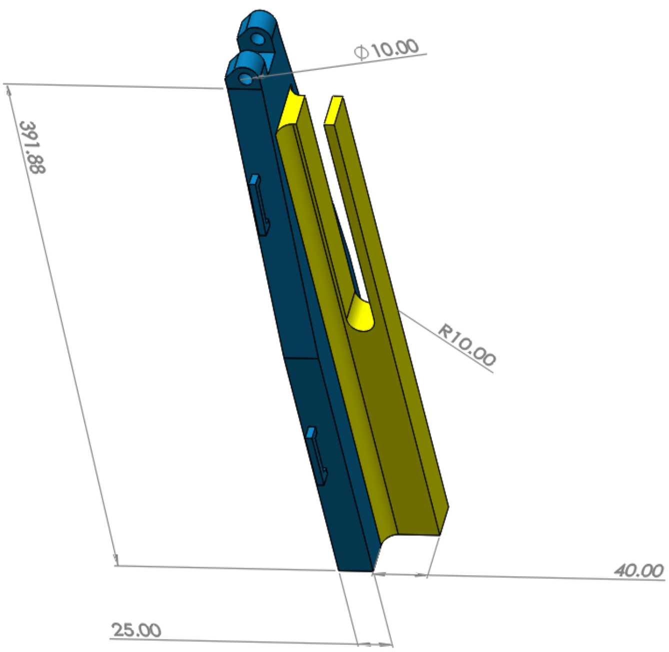


Fig 18: Under Thigh Support

(Source – own source)

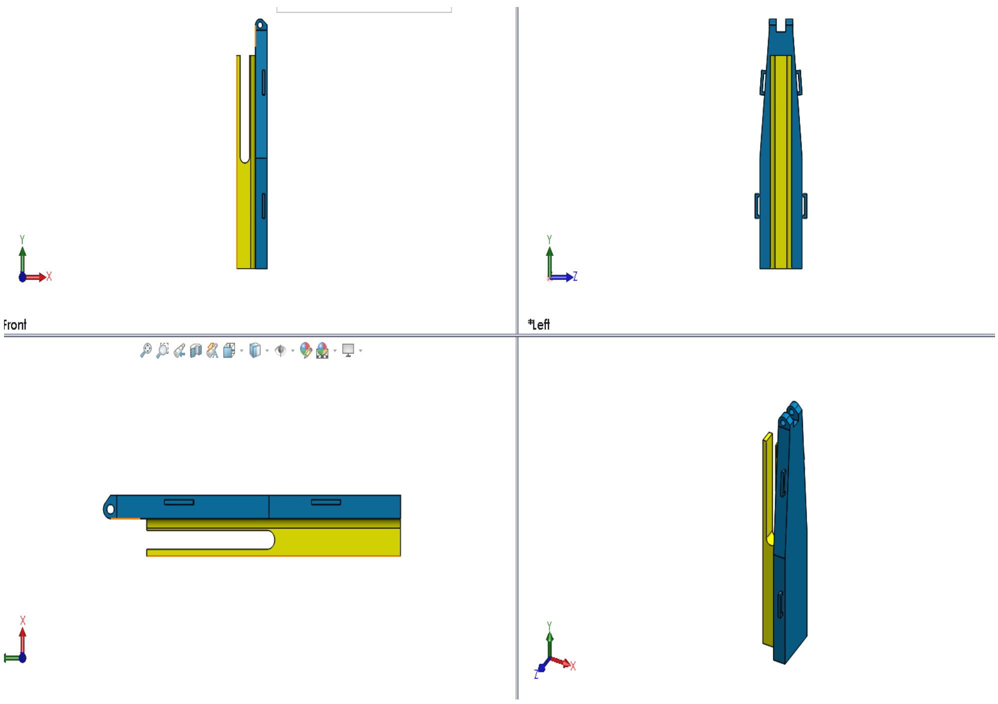


Fig 19 Under Thigh Support Sectional View

Source: Own source

4.1.2 Calf Support

This part is connected to the lower part of the body. Where the lower end of the part touches the ground as a stand, and there is also a hook for attaching the Velcro to strap it around the shin. Figure No: shows the dimension of the part. The material assigned for this part is Ductile ron (SN).

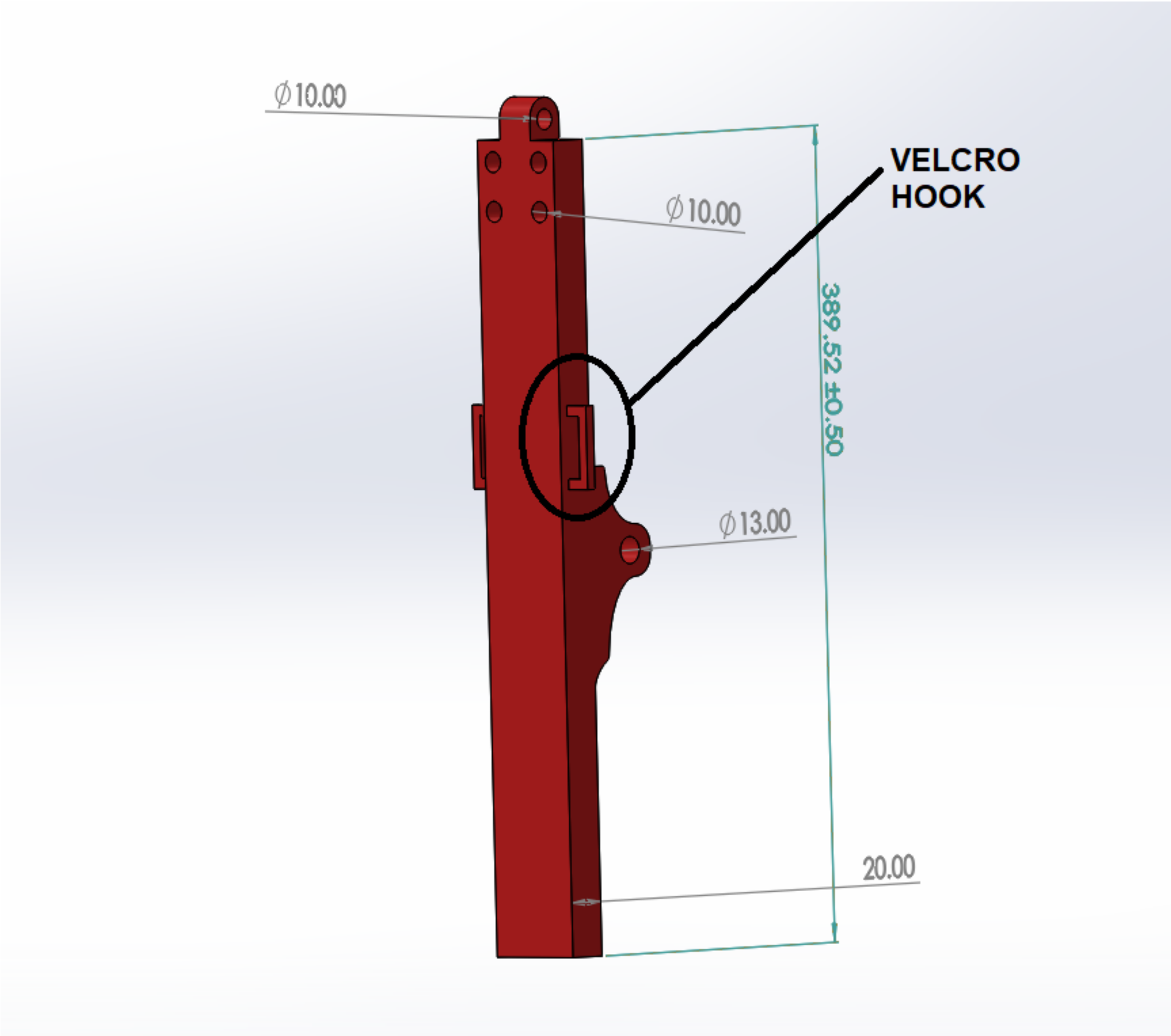


Fig 20: Calf Support

Source: Own source

4.1.3 Damper

This part is connected to the lower part of the body. Where the lower end of the part touches the ground as a stand, and there is also a hook for attaching the Velcro to strap it around the shin. Figure No: shows the dimension of the part. The material assigned for this part is Ductile Iron (SN) (Ti-3Al-8V-6Cr-4Mo-4Zr (SS)).

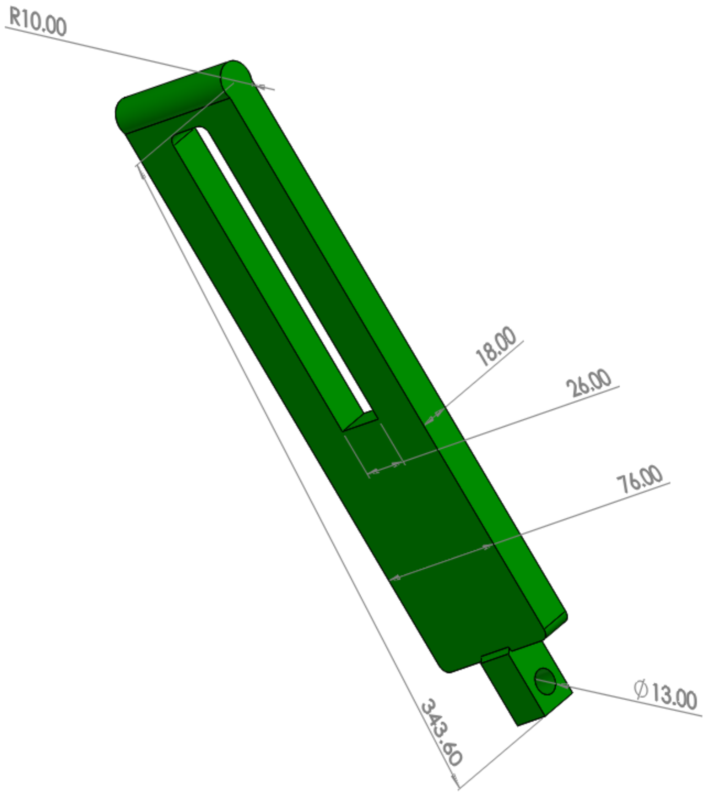


Fig 21: Damper

Source: Own source

4.1.4 EXOSKELETON COMPLETE ASSEMBLY

The assembly part is the combination of all the components. The under-thigh support and the calf support are connected and fixed using round head rivet pins DIN 660. The damper is attached to the calf support and fixed with M6 bolts and tightened, and the other end of the damper is inserted into the circular slot portion cut beneath the under-thigh support and where it can move freely. So that it can be rotated up to 180˚ to 120˚. So, the seating position of the exoskeleton is limited only to 120˚. Therefore, workers can easily sit without any confusion.

There are slots provided for Velcro bands so that the exoskeleton can be attached using straps to the human body.

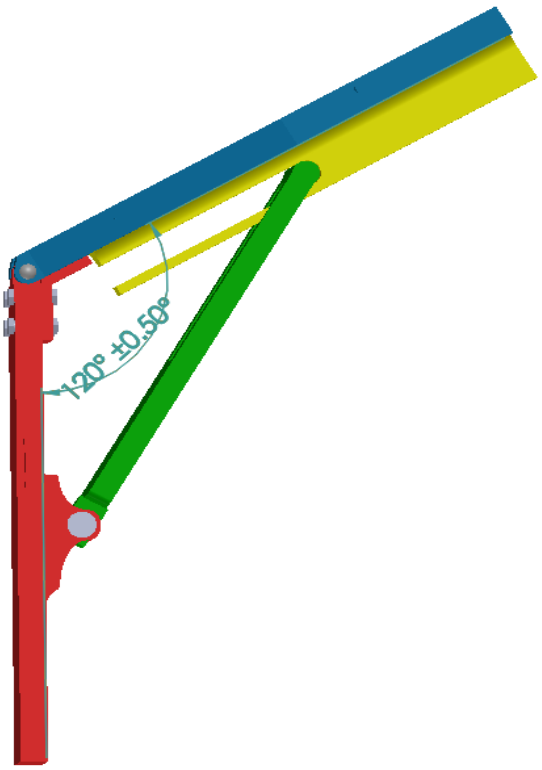


Fig 22: Exoskeleton Assembly

Source: Own source

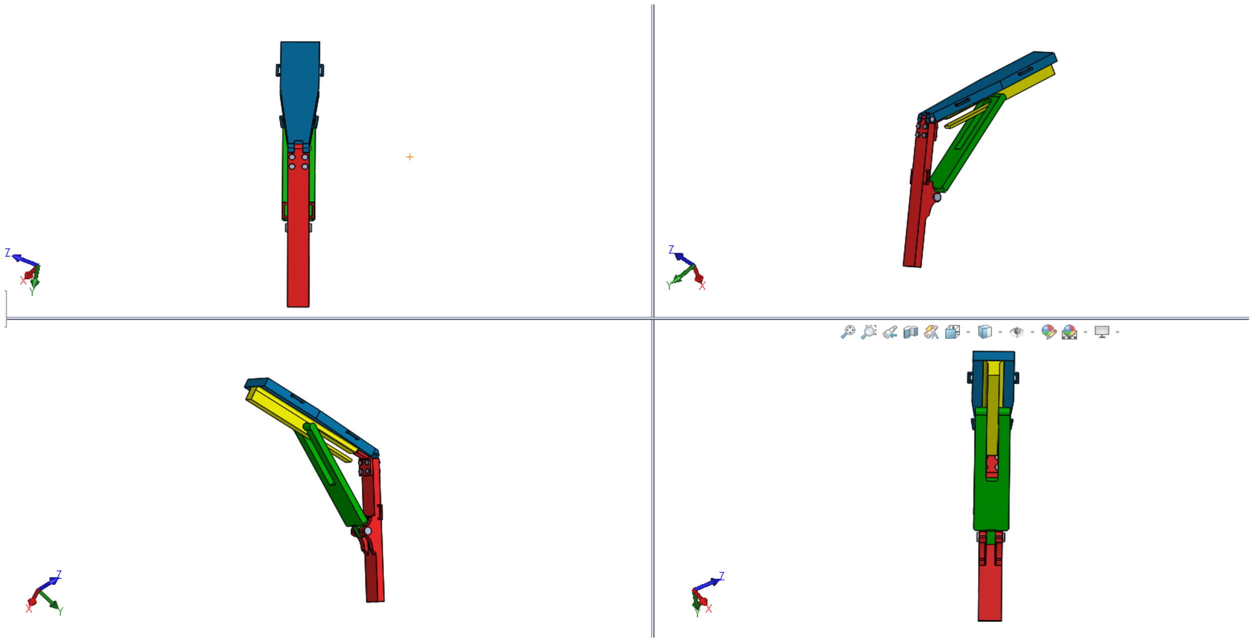


Fig 23 Assembly sectional view

Source: Own source

4.2 MATHEMATICAL CALCULATIONS

Consider that the total body weight of the subject is 100 kg. So, the average weight of each body part follows:

- Human head weighs around 7.30% of total body weight which is 7.30% × 100 kg = 7.30 kg.
- 50.80% of the human body weight is at the trunk portion (chest, abdominal section, and back), therefore 50.80% × 100 kg = 50.80 kg,
- Each thigh of the human body is 9.88% of total body weight which is 9.88% ∗ 100 kg = 9.88kg,
- Lower leg or the shin portion of the leg weighs around 4.65% of total body weight which is 4.65% × 100 kg = 4.65 kg,
- Upper arm that reaches from shoulder deltoids to elbow joint weighs around 2.7% of total body, weight which is equal to 2.7% × 100 kg = 2.7kg,
- Forearm weighs around 1.80% of total body weight which is 1.80% × 100 kg = 1.8 kg,
- Foot weighs around 1.45% of total body weight which is 1.45% × 100kg = 1.45 kg,
- One hand weigh around 0.66% of total body weight which is 0.66% × 100 kg = 0.66 kg.

So, the total weight that acts where the user sits, or the under-thigh support of the exoskeleton is the sum of weight of the body parts except the lower leg and shin.

Therefore, the total effective weight of the body parts acting on the exoskeleton = head weight + trunk weight + weight of two thighs + weight of two arms + weight of two hands.

Total Weight = 7.3 + 50.80 + (2 × 9.88) + (2 × (1.8+2.7)) + (2 × 0.66) = 88.18 kg

As we know the exoskeleton is attached to both the legs hence the weight distribution will be half of the total weight calculated

Therefore, Weight acting on one exoskeleton = Total Weight / 2 = 88.18/2 = 44.09 kg

Thus, according to Newton's second law of motion Force is the product of mass and acceleration.

$\underline{F = m*a}$

Here Acceleration A can be replaced by acceleration due to gravity ‘g’

$F = m \times g$

$F = 44.09 \times 9.8\ m\ s^{-2}$

$F = \underline{432.08\ N}$

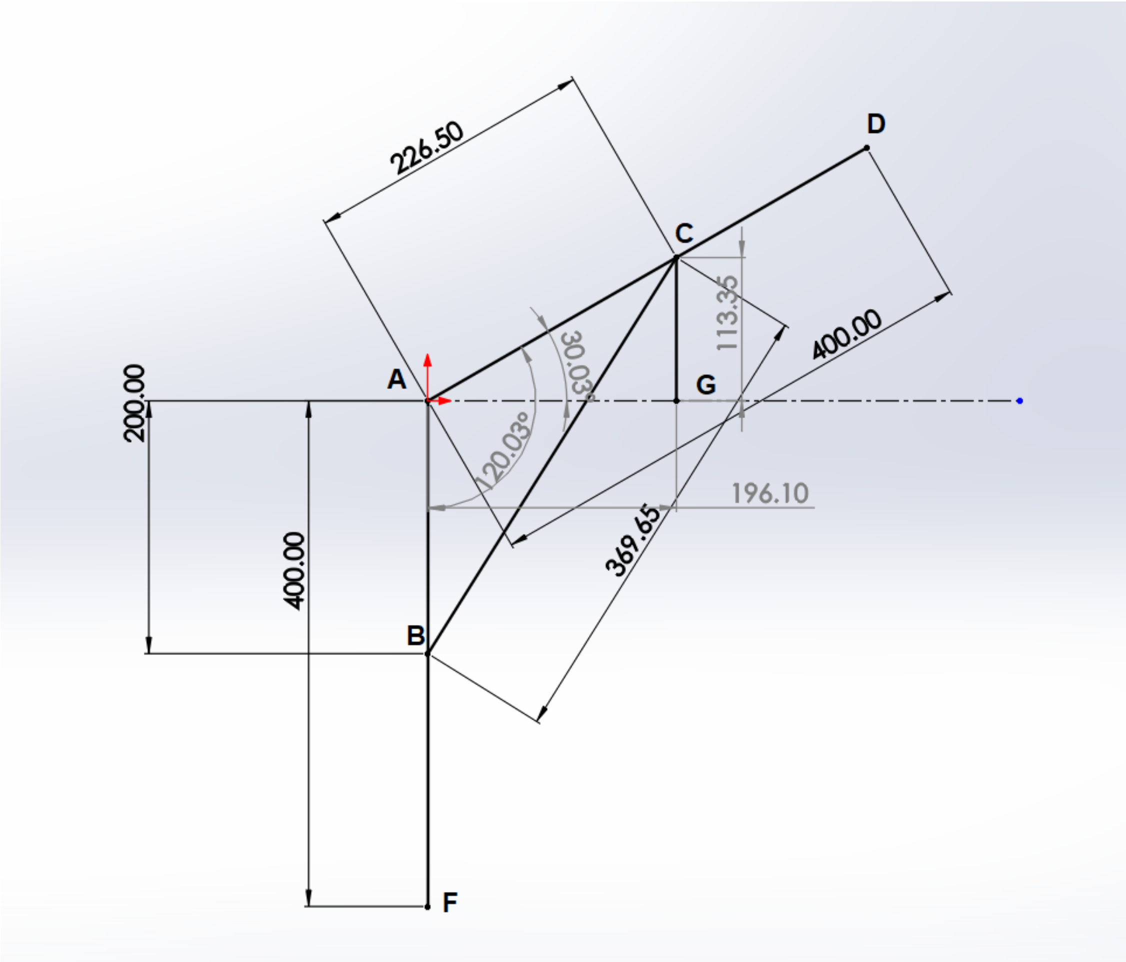


Fig 24 Sketch and measurements

Source: Own source

The force applied at the point C, the moment is about A

$$\Sigma M = 0$$

The sitting posture is at 120˚

as from the triangle AGC

$$\theta = 30^\circ$$

therefore, the sum of moment = 0

$$F_{total} \times \cos 30^\circ \times 19.61 + Fc \times \cos 30^\circ \times 22.65 = 0$$

$$432.08 \times \sqrt{3}/2 \times 19.61 + Fc \times \sqrt{3}/2 \times 22.65 = 0$$

$$7337.910 + Fc \times 19.28 = 0$$

$$Fc = - 7337.910 / 19.28$$

$$Fc = -380.596 \, N$$

Here the force on the point C is negative which means it is a downward acting force.

4.3 COMPUTER ANALYSIS - FINITE ELEMENT SIMULATION

In order to find the maximum weight that the product can bear, a finite element is carried out on the chair-less chair. The maximum load which can be added to this chair-less chair is 50 kilograms, based on the finite element test. If the weight is slightly higher than this value, the chairless chair damper will start bending, so there will be a break. The study was carried out at a position of 120 degrees, where the greatest stress on the joints and beams would take place.

4.3.1 Displacement Analysis

Max displacement takes place at the end of the under-thigh support structure. The max deflection is 0.0127 mm. At other stages, there is insignificant displacement. 0.0114mm, which nullifies a displacement since there is an elastic existence and no irreversible beam deformation occurs.

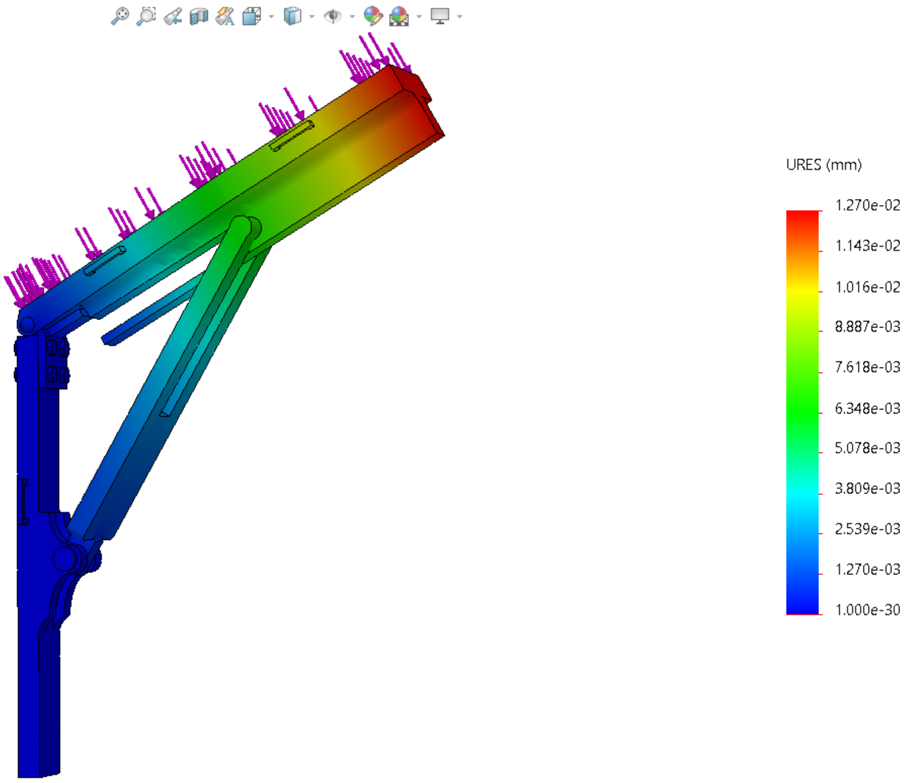


Fig 25: Displacement Analysis

Source: Own source

4.3.2 Von Mises Stress Analysis

The stress analysis of von mises tells us that maximal stress is located between the damper and the top beam at the nodes. *3.768e+06 N/m2* with peak tension. Minimum tension in the protection of the thigh and shin

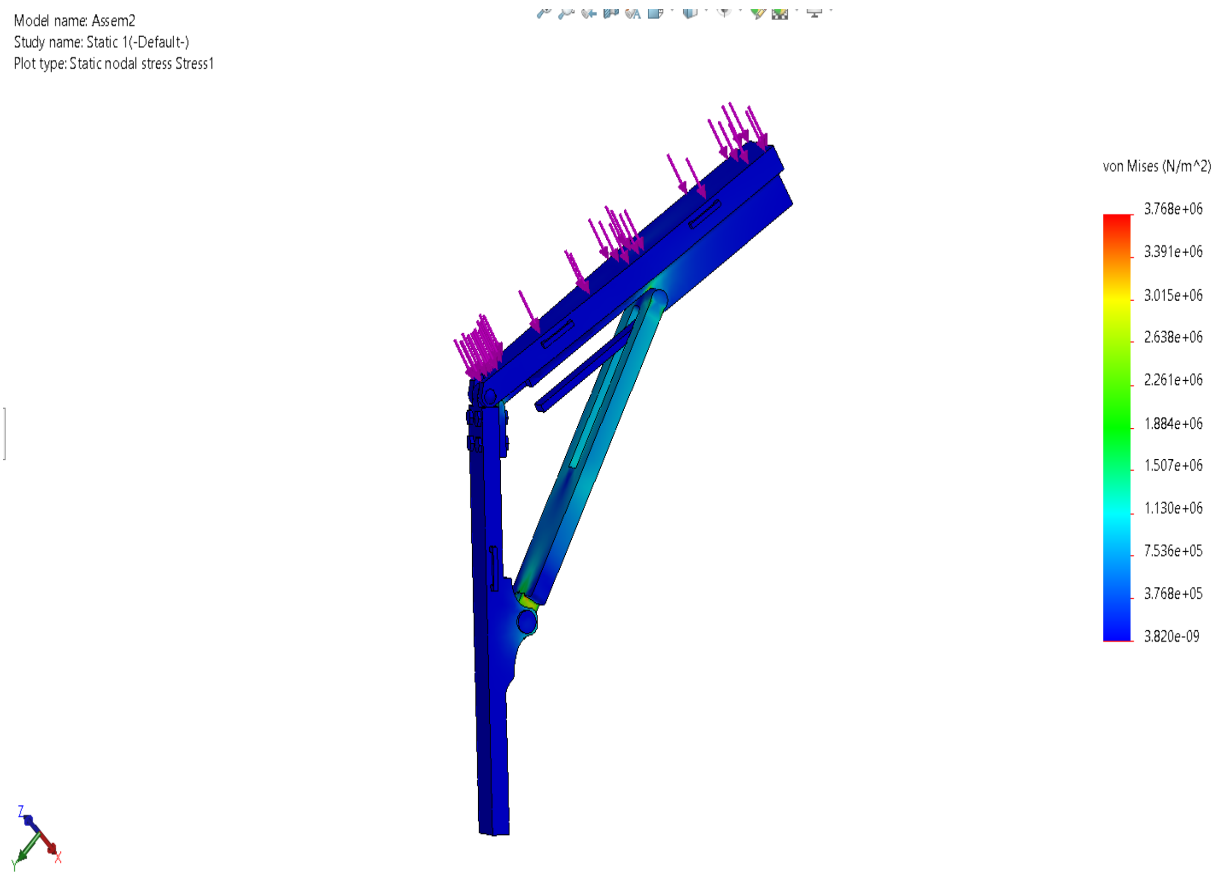


Fig 26: Von Mises Stress Analysis

Source: Own source

4.3.3 Equivalent Strain Analysis

The maximum strain encountered at the knuckle joint is around *2.426*e-05*. Most of the pressure occurs in this area and even in the calf support damper joints. These happen because of the handling of loads and these are within the limits of the material used.

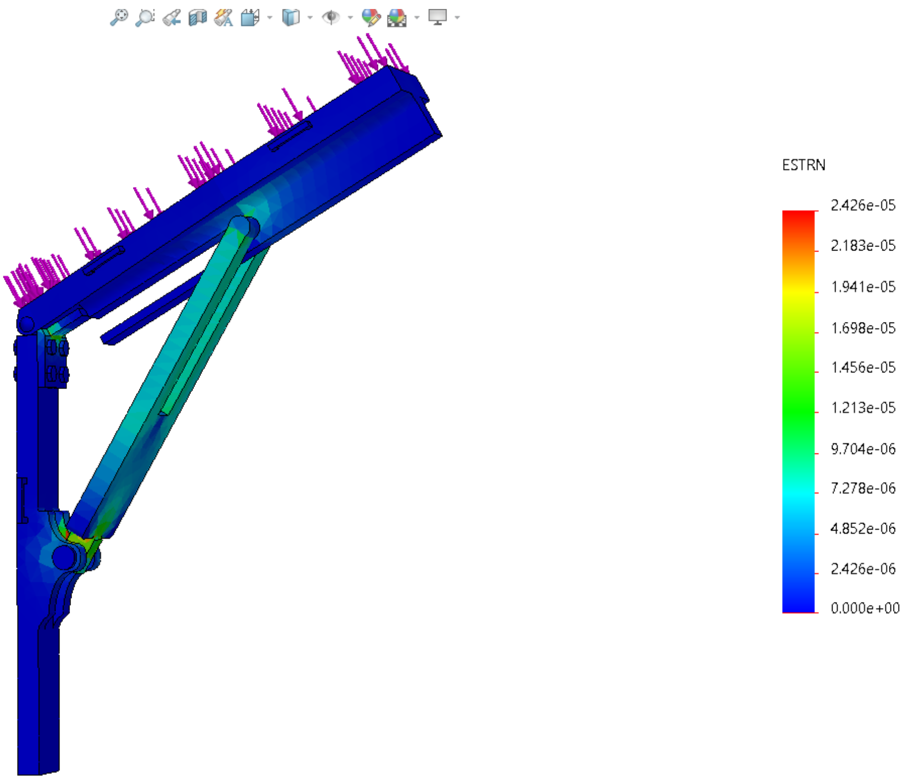


Fig 27: Equivalent Strain Analysis

Source: Own source

So, the final product weighs 1,938 kg per leg and offers supportive seating and Velcro straps that provide the body with easy and proper Chairless Chair Exoskeleton strapping.

5. MY RESULTS

As a company, which produces automobile parts and body structures for the leading manufacturers in the world, the main motto of the firm must be consistency and good quality production. After studying the entire culture of the company, production rate and consistency in production of the products are at high risk. The company was not able to deliver the product at the promised time. While examining deeply through the working culture of the company, I came to know the real reason behind the decrease in the production outcome. The reduced pace of the work and wastage of working time by taking frequent ease off intervals by the workers are the real reason behind the low productivity. And this is because of the muscle fatigue due to, musculoskeletal issues, and the lower back pain due to prolonged standing. The standing posture working atmosphere is most hard in stable resistance spot welding, so I proposed to change the working posture to a sitting instead of standing; then the result was astonishing.

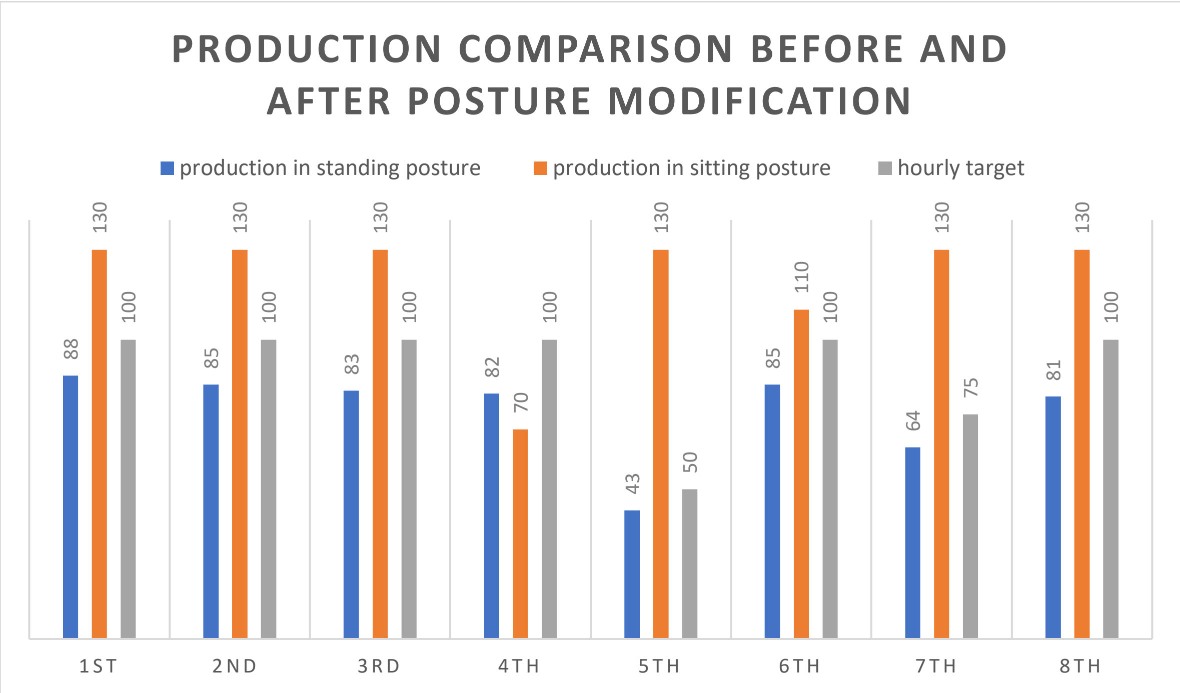


Fig 28: Production Comparison Chart (before and after working posture modification)

Source: Own source

So, introducing a normal chair to the working atmosphere was the next phase of the initial development to solve the problem, but this brought space management issues in the working area. This brought me to a conclusion that when the working posture change due to the introduction of the sitting posture brought an astonishing result but normal chair will have problems with space management in the work station, so this increases the chance of chairless chair exoskeleton because it is mobile and also provide a sitting posture. Thus, the chairless chair exoskeleton is the perfect alternative and solution for the situation. And one more important result is that while working in the sitting posture the workers were not taking too many frequent intervals to ease the muscular pain and fatigue.

The production will increase by 20-25% without applying any force or pressure on the employees.

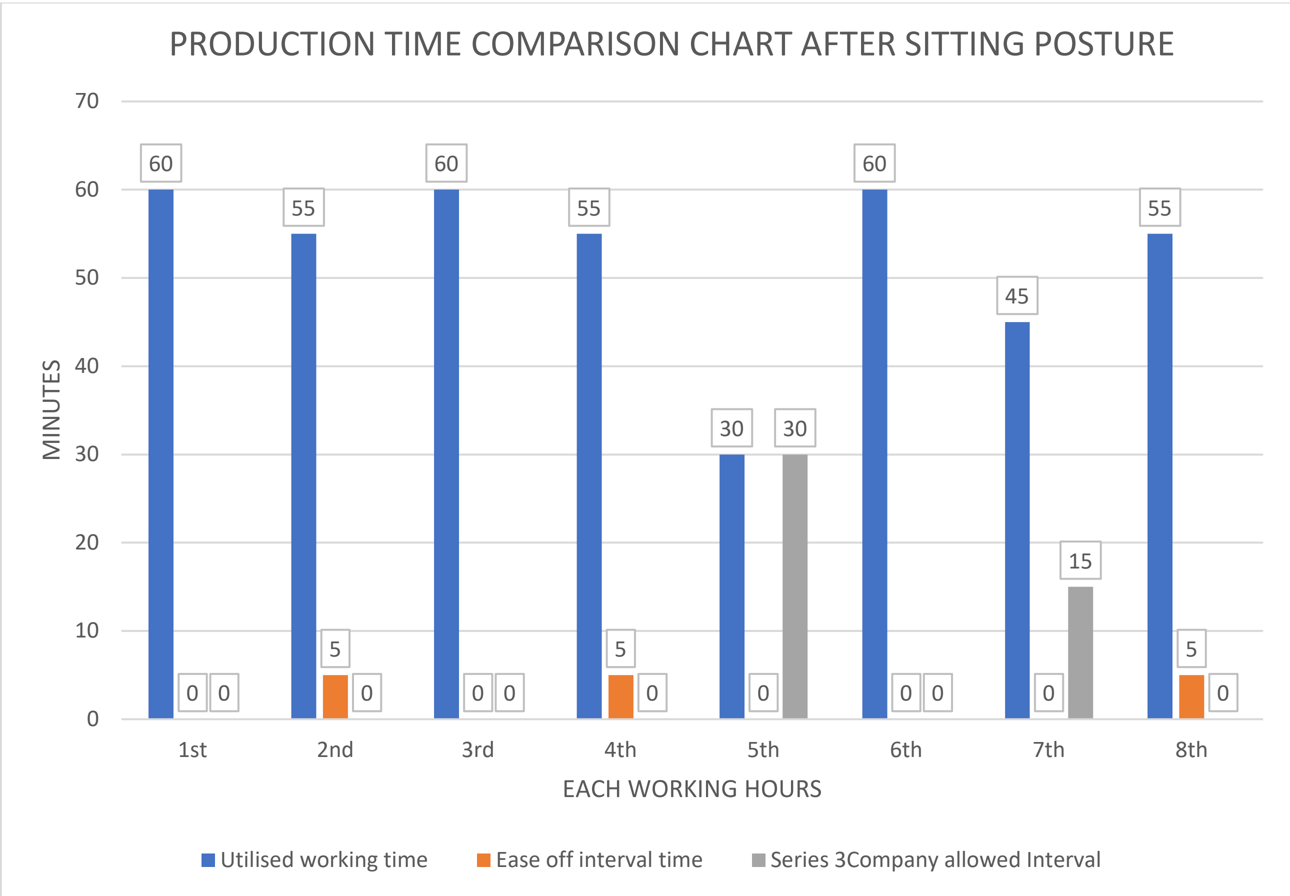


Fig 29: Production time comparison chart after sitting posture

Source: Own source

From the chart above we can see that maximum ease off intervals taken by a worker is about is 3 times and the duration are reduced 15 minutes which is decreased to 20-25% as compared to the previous examination.

The design and development were undertaken to build the 3D model chairless chairs that are used to minimize exhaustion due to continuous work. The secure load that can be added to this chair is 100 kilograms less than the chair (100 kg individual tested). If the load is slightly higher than this value, the damper hinge may start bending at the top of the exoskeleton, so failure can occur. In that case, we should replace the not only the damper but the entire exoskeleton of material example Titanium to prevent this from occurring in the future so that the chairless chair should support more. The weight of the exoskeleton chair is less than 4 kilograms with a weight of 1.93 kg per leg. It is not too heavy for us, but we can replace the aluminum structure with carbon fiber if we want to reduce the weight in the future, as well as use thinner and stronger dampers. Fiber glass is a good strength to weight ratio component, but it is quite expensive.

6. CONCLUSION

In conclusion, improving the working atmosphere of the company can bring many auspicious results. The main motto of the firm, which produces automobile parts and body structures for the leading manufacturers in the world, must be consistency and good quality production. If we combine the culture of the company, the production rate and the consistency in production of the products, we can safely assume that those given factors are at high risk - The company was not able to deliver the product at the promised time.

Muscular fatigue; as I have explained above, muscle fatigue caused by extended standing costs the organization 40 working days, or around two months, and results in less productive personnel suffering from lower back discomfort, lumbar spine disorders, varicose veins, and other health problems. But after modifying the working atmosphere by bringing the changes in posture management, this improves the total working atmosphere by a big degree. A second important factor, that has a bigger impact that one normally believes, is the mental state in such situations. Before the implementation of the exoskeleton chairless chair, workers went on more breaks - not because of tiredness. but because of the posture pressure on the spine while working on foot in a a a half leaned forward position. On those breaks, most of them smoked cigarettes, which is a coping mechanism for being stressed out because of the pain.

This brings us back again to the first issue, bad posture. And this is a domino effect circle where workers have a hard time getting out of it. But with the help of the exoskeleton chairless chair, back pain would soon be non-existent, or at least brought down to a bare minimum. The back pain solution would also have a big effect on the mental state of mind of the worker. They would work more efficiently, produce higher production numbers, and have a healthier posture with the help of the exoskeleton chairless chair.

With the health issues created by the workspace being solved, we can finally talk about a stressless working atmosphere and environment, numbers of workers taking sick leave due to musculoskeletal issues would start to drop, and on top of it, the replacement of traditional chairs with exosceletal chairs with no seats would greatly improve the space management of the workplace. The workspace with the old/previously installed chairs had less space to move around freely and the chairs were bound to the place, where they were installed with close to no option of manoeuvrability, forcing the worker to work nonstop in a posture, not healthy and welcoming for the body at all.

The combination of all the combined solutions to the health, space and workload issues mentioned above, brings us to the most important aspect of why I decided for such topic in my diploma paper and the main aspect of why all those solutions are important and intertwined.

The increase in production. Since something is done to improve the work space or work schedule of workers, it decreases the stress and tension and improves the well-being and health of the workers. This also increases production in the company. The more productive the workers, the more they produce, or in other words, the number of produced goods rises exponentially; hence the company achieves higher productivity goals or can raise the production numbers even further - more punctual and quality delivered goods to the customers.

The final important result is that while working in the sitting posture the workers were not taking too much frequent intervals to ease the muscular pain and fatigue and the production would increase by 20-25% without applying any force or pressure on the employees.

All in all, the chairless chair exoskeleton is the perfect alternative and solution for the situation. The design and development of the exoskeleton chairless chair was created with the ideology to help the worker and indirectly help the company as well. Helpful to improve efficiency and to reduce the employee's work pressure and musculoskeletal problems. It is also a 100% cost-saving initiative for the company and a 100% health initiative for the worker.

7. RESOURCES

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