OPTIMISING ERGONOMIC DEVELOPMENT AT A MANUFACTURING COMPANY

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Abstract

During our investigations at the electronics manufacturing company, we encountered numerous ergonomic challenges, the resolution of which had a significant impact on productivity and employee well-being. The aim of our research is to collect and systematise the ergonomic improvements that have already been implemented and to identify opportunities for future development. Our ergonomic recommendations are intended to assist similar companies in the ergonomic design and implementation of manufacturing processes, thereby increasing efficiency and employee satisfaction. This approach not only increases productivity, but also contributes to the health and well-being of employees, resulting in long-term sustainability and success.

Keywords: *occupational safety, manufacturing, human-machine interaction, ergonomics*

1. Introduction

Ergonomics is becoming increasingly important in the modern industrial environment. Based on the experience gained at the electronics manufacturing company studied, it can be said that production efficiency is closely related to the physical strain and comfort of workers.

Ergonomic knowledge can be applied through compliance with legal regulations, harmonized standards, or other equivalent solutions.

Here are the main existing ergonomic standards grouped together:

- Main areas covered by ergonomic standards (ICS 13.180 Ergonomics),
- Ergonomic principles,
- machine safety series,
- issues related to mental workload,
- temperature environments,
- design of control centres,
- environmental factors (noise, lighting, vibration, climate),
- issues related to display screens (ISO 9241 series).

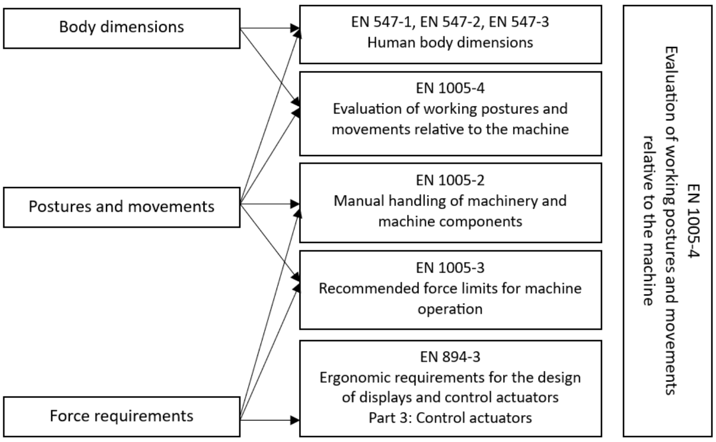

Figure 1. *Relationship between physical performance characteristics and standards* (adapted from Szabó, 2011)

2. Systematisation of ergonomic challenges

The problems identified include: overload caused by manual material handling, repetitive, monotonous movements, poor posture and non-ergonomic working environments. In the long term, these can lead to musculoskeletal disorders (MSDs), which reduce workers' ability to work and increase absenteeism. In addition to physical strain, mental strain can also increase if the working environment does not support comfortable and efficient work.

3. Ergonomic analysis methods used

In our research, we compiled a list of analysis methods that can be used in the field of ergonomics (Dul & Weerdmeester, 2008), the results of which are presented in Figure 2.

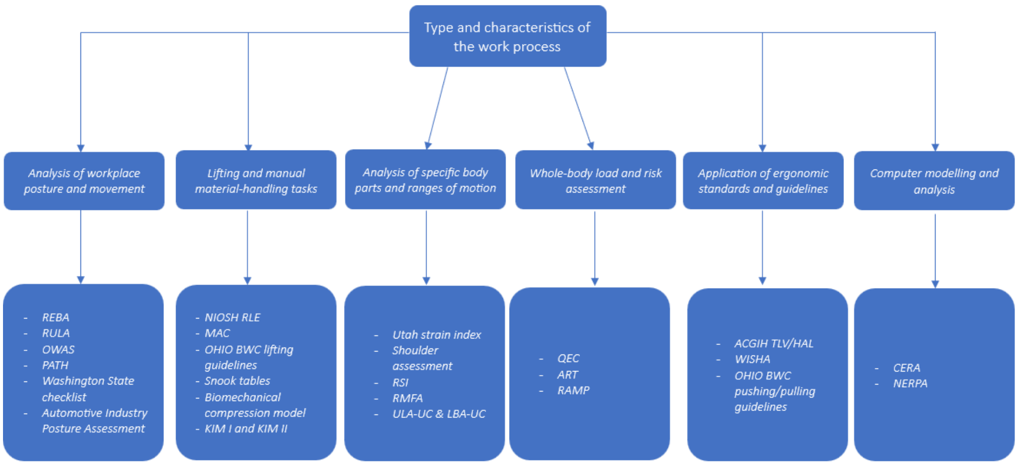

Figure 2. *Classification of analysis methods according to the type and characteristics of the work process*

In order to select the appropriate analysis and evaluation method, the different methods are explained in more detail below:

Analysis of posture and movement at work

- REBA (Rapid Entire Body Assessment): Rapid assessment of total body load in different postures.

Classification of ergonomic analysis methods

- RULA (Rapid Upper Limb Assessment): Assessment of upper limb, head and trunk posture.
- OWAS (Ovako Working Posture Analysis System): Analysis of body positions and their risks.
- PATH (Posture, Activities, Tools, and Handling Analysis): Observation and analysis of workplace postures and activities.
- Washington State Precautionary and Hazard Checklist.

A tool for analysing work postures and risk factors.

- Automotive Posture Assessment: Analysis of postures and movements used in the automotive industry.

Lifting and manual material handling tasks

- NIOSH RLE (National Institute for Occupational Safety and Health Lifting Equation): Assessment of lifting tasks.
- MAC (Manual Handling Assessment Charts): Risk assessment of manual material handling tasks.
- OHIO BWC Lifting Guidelines: Guidance on lifting tasks.
- Snook Tables: Assessment of loads during lifting, pushing and pulling.
- Lumbar Pressure Model: Assessment of lumbar load during manual material handling.
- KIM I (KIM-LHC) and KIM II (KIM-PP): Risk assessment for lifting, pulling and pushing tasks.
- RAPP (Risk Assessment for Pushing and Pulling): Risk assessment of pulling and pushing tasks.

Specific physical activity and range of motion analysis

- Utah Shoulder Movement Assessment: Assessment of shoulder joint movement load.
- RSI (Repetitive Strain Index): Assessment of load caused by repetitive movements.
- RMFA (Rapid Movement Frequency Assessment): Assessment of the frequency of rapid and repetitive movements.
- ULA-UC & LBA-UC: Assessment of the range of motion of the upper and lower limbs.

Full body strain and risk assessment

- QEC (Quick Exposure Check): Quick analysis of workplace risk factors.

Classification of ergonomic analysis methods

- ART (Assessment of Repetitive Tasks): Assessment of the load of repetitive work tasks.
- RAMP (Risk Assessment and Management Process): Assessment of whole-body load and risk.

Application of ergonomic standards and guidelines

- ACGIH TLV/HAL (American Conference of Governmental Industrial Hygienists Threshold Limit Values/Hand Activity Level): Threshold values for manual workloads.
- WISHA (Washington Industrial Safety and Health Act): Workplace ergonomic standards and guidelines.
- OHIO BWC push-pull guidelines: Guidelines for pushing and pulling tasks.

Computer modelling and analysis

- CERA (Computerised Ergonomic Risk Assessment): Risk assessment based on computer modelling.
- NERPA (Nordic Ergonomic Method for the Risk Assessment of Repetitive Work).

We used several internationally recognised methods at the company under review, which are as follows:

- The REBA (Rapid Entire Body Assessment) and RULA (Rapid Upper Limb Assessment) methods were used to examine the overall posture of employees and the strain on their upper limbs (McAtamney & Corlott, 1993, Hignett & McAtamney 2000).
- The MAC (Manual Handling Assessment Charts) and RAPP (Risk Assessment of Pushing and Pulling) methods provided support in analysing the risks associated with material handling (HSE, 2004).

The analytical methods used made it possible to rank the most critical work processes from an ergonomic point of view.

4. Identification of ergonomic problems and proposed solutions

4.1. Moving heavy equipment

The process: Moving heavy modules between different points in the production hall places a significant physical strain on machine maintenance personnel. The combined weight of the modules and the transport trolley varies between 700 and 1000 kg, depending on the type, with the transport trolley alone weighing 300 kg. The average distance between the workshop and the production lines is 100 metres, which employees have to cover regularly. The problem arises from the fact that moving heavy loads is extremely physically demanding for workers, as confirmed by ergonomic analyses. Two people are responsible for moving the loads, which further increases the strain due to the need for coordination and thus the risk of injury. Ergonomic analyses have shown that the current methods are not suitable for maintaining the health of workers. A further problem is that the rear wheels of the transport trolley are not suitable for pushing/pulling in a straight line, as their direction cannot be fixed, causing them to slide sideways, which makes movement even more difficult. When towing, the rear wheels must be fixed in a straight line to prevent sideways movement, which could pose a further risk of accident.

Recommended ergonomic improvement: Install a frame on the module transport trolley and use an electric towing aid to move the trolley. In addition, install lockable wheels on the module transport trolleys.

The following benefits can be expected from an ergonomic point of view:

- Reduced physical effort: The electric towing aid significantly reduces the physical effort required by maintenance personnel, as the machine does the heavy lifting. This is particularly important for loads of 1000 kg, which can be extremely strenuous to move manually.
- The use of electric traction aids reduces the risk of musculoskeletal disorders (MSDs) such as back pain and muscle strain, as maintenance workers do not have to push or pull heavy loads.

Advantages of using an electric towing aid:

- Reduced physical effort: Electric tow tugs significantly reduce the physical effort required by maintenance personnel, as the machine does the heavy lifting. This is particularly important for loads of 1000 kg, which can be extremely difficult to move manually.
- Ergonomic benefits: Using an electric tow tractor reduces the risk of musculoskeletal disorders (MSDs) such as back pain and muscle strain, as maintenance workers do not have to push or pull heavy loads.
- Faster and more efficient work: The electric towing aid makes moving heavy loads faster and more efficient, which increases the speed and efficiency of maintenance processes.

- Less time and energy: Maintenance workers spend less time and energy moving loads, allowing them to devote more time to actual maintenance tasks.
- Reduced risk of accidents: Using an electric tow assist reduces the risk of accidents and injuries, as maintenance workers are less likely to have to move heavy loads manually, which can often lead to muscle and joint injuries.
- Stopping distance: When left unattended and the throttle is not engaged, the tow assist automatically applies the brakes, bringing the vehicle to a stop almost instantly.
- Wider field of vision: Pushing the trolley and module has been replaced by pulling the structure, so the maintenance technician operating the tow assist can take advantage of the benefits of pulling and see oncoming traffic without being obstructed by the machine.
- Better manoeuvrability: The ergonomic design and ease of use of electric tow tugs enable more precise and safer movement, even in confined spaces.
- Lower healthcare costs: Reduced physical strain and lower risk of accidents mean lower healthcare costs, as maintenance workers are injured less often.
- Increased work efficiency: More efficient work and less waiting time make the company more cost-effective overall.

The introduction of electric tow tractors therefore not only makes the work of maintenance personnel easier, but also increases safety, efficiency and cost-effectiveness (WEB_1).

4.2. Ergonomic challenges of product handling

The process: The worker removes the part from the box and packaging and places it on the trolley. Once assembled, the product is transferred to the test trolley. When removing the part from the box and packaging, the worker puts excessive strain on their forearms and upper arms. The part weighs 9 kg.

Recommended ergonomic improvement: Use of a Hapo front exoskeleton, which can reduce strain on the arms by supporting the elbows. This reduces the risk of MSDs. Advantages:

- very light: 1.3 kg,
- does not require an external power source,
- putting on time: <50 s,
- removal time: <20 seconds,
- breathable material.

Expected results after development: The load is easier to lift and move because, thanks to the selectable preload, the exoskeleton structure takes on the 2x2 or 2x3 kg load, thus reducing the strain on the elbow (and upper arm).

The proposed ergonomic solution can also be implemented in other areas with a different type of exoskeleton (APEX 2 Herowear exoskeleton), such as:

- Picking finished products;
- PCB loading process;
- Moving chemical goods in MRO warehouses.

4.3. Picking finished products

When picking finished products, workers often have to move heavy boxes, which places a significant physical strain on them (Figure 3). Due to the weight of the boxes, workers are forced to adopt awkward postures, such as bending, lifting and twisting, in order to reach and position the boxes correctly. These positions place constant strain on the spine, particularly the lumbar region, which can lead to serious health problems in the long term, such as herniated discs. This problem not only jeopardises the health of employees, but also reduces work efficiency, as workers are often forced to take sick leave or work at reduced capacity. To solve this problem, it is important for employers to introduce ergonomic improvements.

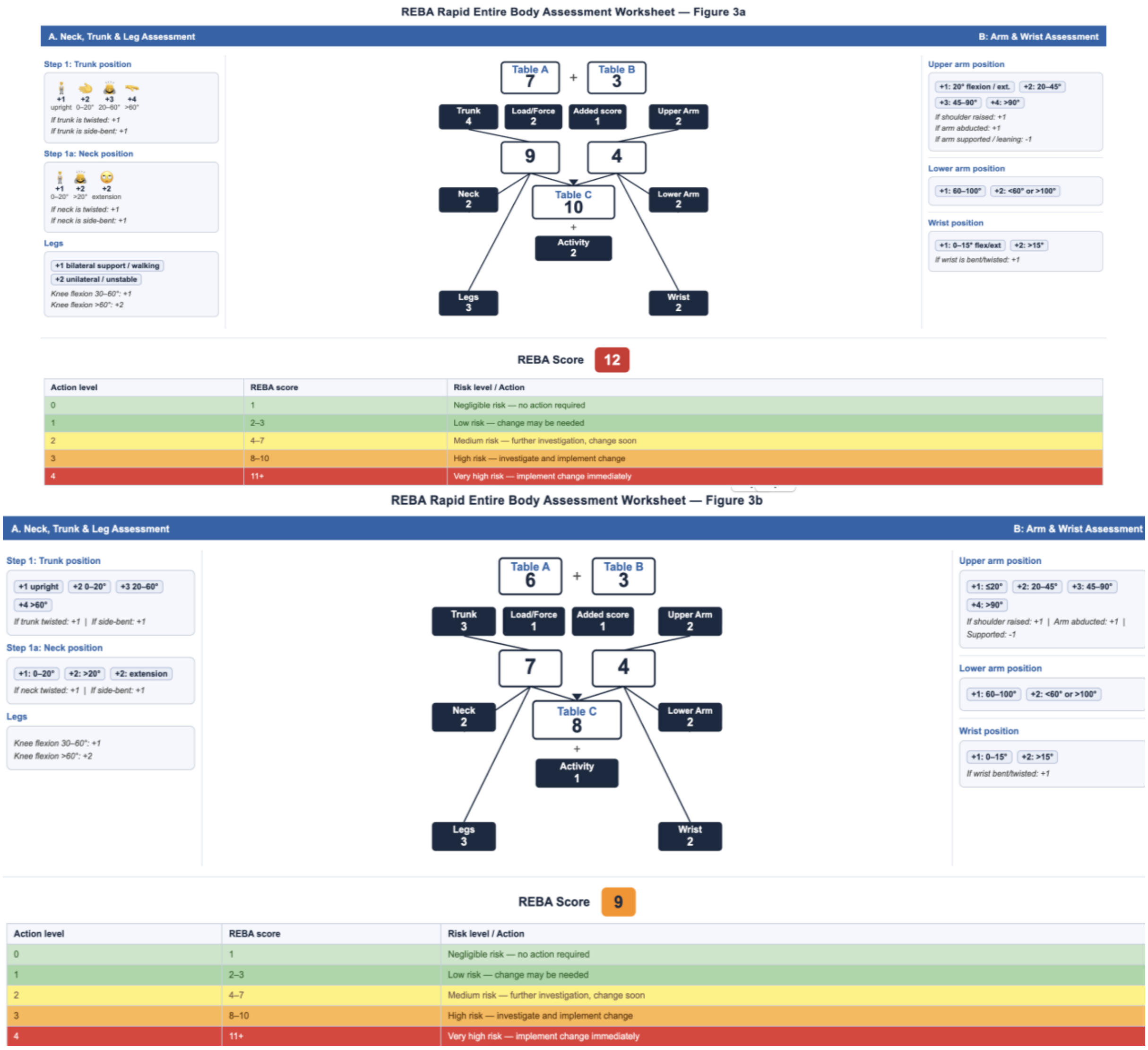

Figure 3. *Analysis of the finished product picking process under normal conditions and with the aid of an exoskeleton*

4.4. Moving PCB storage magazines

A PCB storage magazine is a device used to store and transport printed circuit boards (PCBs). These magazines are usually equipped with electrostatic discharge (ESD) protection to protect the PCBs from damage. Magazines are available in various sizes and capacities and often feature quick-adjust locking mechanisms for ease of use. Another significant musculoskeletal impact is the loading and unloading of magazines filled with PCBs into machines and magazine storage trolleys (Figure 4). When lifting these, workers must also concentrate on preventing the PCBs from slipping out of the magazine, which means they can pay less attention to the correct lifting technique (Waters et al., 1993). The total weight of the magazines often exceeds the maximum that can be lifted by one person, which causes further problems. In the above case, it is necessary to require that at least two people lift the magazine. There is usually no second person available on site to do this, which slows down the movement process. To overcome this, the aim is to create a moving mechanism that allows the magazines to be loaded and positioned on storage trolleys and machines without the use of significant muscle power.

Design result

The electric magazine lift is an innovative device that facilitates the movement and positioning of heavy magazines during manufacturing processes. The ergonomic design of the device reduces physical strain and increases work efficiency. The electric lifting system enables fast and precise movement, while the built-in battery provides the necessary mobility in the production hall. The device does not require a special licence to operate, so it can be easily integrated into existing work processes and contributes to the health of employees.

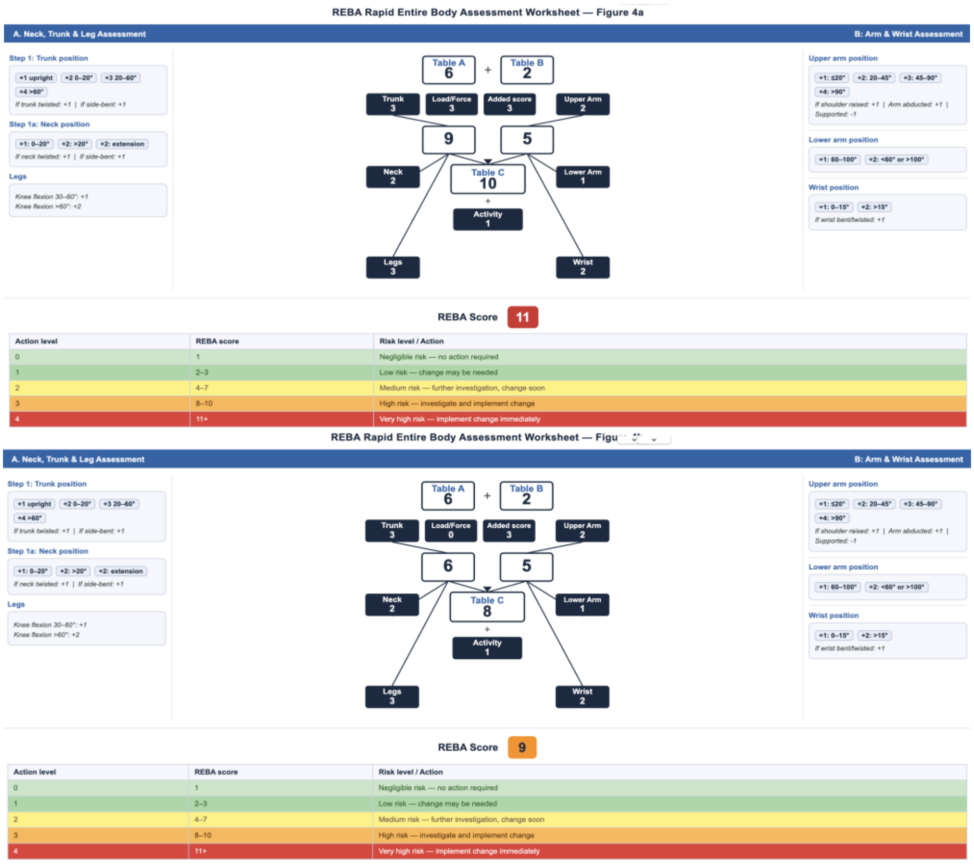

Figure 4. *Analysis of the PCB loading process under normal conditions and with the aid of an exoskeleton*

Ergonomic improvements: The trend of the future

The relative positions of machines in the production hall often change, so the route between picking up and putting down the magazine may also change. A battery is required for the desired mobility.

The system must also be suitable for 4-shift production, so a battery with sufficient capacity must be selected. High fluctuation must be taken into account, and therefore the operator authorisations for lifting machines. The aim is to have trained personnel operate the machine as soon as possible. If internal training is sufficient for the operation of the lifting machine, this would greatly facilitate its use, but considering another possible solution, according to Decree 47/1999. (VIII. 4.) GM on Lifting Equipment Safety Regulations, if it is not subject to the legislation on lifting equipment, it may be used by employees working with the machine in question after internal training.

5. Development opportunities and recommendations

We recommend the following for future developments:

- Introduction of Total Ergonomic Management (TEM), which deals with ergonomic issues in an integrated manner (Schneider et al, 2010),
- Application of user-centred design (UCD) already during the design of work processes, as well as training and feedback – involving employees in development processes.
- In order to achieve the best results, it is important to deepen the ergonomic culture within the company.

Based on our analysis of the ergonomic factors, the following innovative solutions were identified for electronics manufacturers:

Optimisation of workstations and technology

Improvement of the immediate working environment

1. Adjustable desks and chairs: Provide desks and chairs that are height-adjustable so that all employees can work comfortably.
2. Adequate lighting: Ensure adequate lighting to reduce eye strain and headaches.
3. Anti-fatigue mats: Use anti-fatigue mats at standing workstations to reduce strain on the legs and back.
4. Comfortable chairs: Use comfortable chairs to support the body at standing workstations and reduce strain on the legs, allowing for a standing-sitting posture.
5. Creating a matt working environment: A matt working environment reduces glare for workers, creating more favourable visual conditions and reducing the reflection of harmful rays, e.g. from UV lamps.
6. Refillable gravity storage: It is recommended to refill the rolling gravity storage from the rear, which not only enables the FIFO principle to be implemented, but also allows the continuously emptying parts storage to be refilled without disturbing the workers at the station.

Tools and equipment

7. Ergonomic tools: Provide ergonomically designed tools that reduce strain on the hands and wrists.
8. Easy-to-move tools: Provide easy-to-push, movable tools and trolleys for transporting heavy objects to reduce physical strain.

Ergonomic innovations for electronics manufacturers:

9. Moving trolleys: These can be magazine moving trolleys, pallet moving trolleys or even test head moving trolleys, which can be used to move heavy equipment and raw materials after sliding/rolling them onto the platform. Highly recommended for heavy loads.

10. Suspended electric screwdrivers: Use suspended, counterbalanced screwdrivers to avoid hand, finger and shoulder fatigue.
11. Inspection camera: Magnifying lamps are often used for inspection tasks because they make it easy to spot even very small defects. Currently, a much more favourable and convenient solution is camera inspection, which projects the image from the given area onto a monitor, making it very easy to check the desired part/surface. Its use is important where robots cannot be used economically, but where the accuracy of the inspection is crucial, for example during final inspection.

Work processes and organisation

12. Regular breaks: Ensure that employees have regular breaks to rest and stretch.
13. Task rotation: Use task rotation so that workers do not perform repetitive movements for long periods of time, which reduces monotony and the risk of injury.
14. Training and education: Organise ergonomic training to teach employees correct posture and movements.
15. Ergonomic audits: Conduct regular ergonomic audits to identify and correct potential problems.
16. Employee feedback: Collect feedback from employees on ergonomic improvements and needs. This should be noted on the ergonomic assessment sheet when examining a given workstation.
17. Optimisation of the work area: Optimise the layout of the work area to minimise unnecessary movements and steps. Frequently used or heavier tools and components should be located in the worker’s main work area.

Technological developments

18. Automation, robots: Design and use automated systems, robots and co-bots to perform difficult and repetitive tasks in order to reduce physical strain.
19. Return conveyor belts: Use return conveyor belts for long production lines. If one or more people work on the production line, the conveyor track should be located above the production line if possible. This avoids the concept of machines/technology underneath, which requires the production line to be raised and the construction of separate platforms and podiums for the necessary workstations.
20. Branching conveyor tracks: Automatic conveyor tracks should be installed next to the workstations, which allows for multiple functions to be performed on the production line, even if the products have to pass through several different stations in succession, where a “failed” decision may be made. This allows rejected products to be immediately separated from the good ones.
21. Ergonomic software: Use of ergonomic software to analyse and optimise workstations and work processes.
22. Proper placement of monitors: Adjusting monitors to eye level and at a suitable distance to reduce neck and eye strain. Use of universal monitor mounts to adjust to the different anthropometric measurements of workers.
23. Footrests: Provide footrests at seated workstations so that workers can position their feet comfortably.
24. Virtual reality (VR) training: Use VR technology for ergonomic training so that workers can safely practise correct posture and movements.
25. Reel loader: A reel loader is a specialised device used to supply implanting machines. Its main task is to load reel coils into the feeder, which is essential for continuous and efficient manufacturing processes. The ergonomic design of the device allows for quick and accurate threading, minimising physical strain and increasing work efficiency.

Tools and equipment

26. Adjustable keyboard and mouse pad: Provide adjustable keyboards and mouse pads so that workers can work comfortably.
27. Ergonomic mice and keyboards: Provide ergonomically designed mice and keyboards that reduce strain on the hands and wrists.
28. Easily accessible storage: Place frequently used tools and materials in easily accessible locations so that they can be reached with minimal bending and stretching.
29. Reduce tool weight: Use lighter tools to reduce physical strain.
30. Scales, counters: Scales that can also be used for counting, so that not only the weight but also the number of parts for a given weight can be easily checked.
31. SMD component counter: In the case of unopened, sealed reels, counting can be performed using an X-ray machine set up for this purpose. For opened tape reels, the use of a separate component counting machine is recommended.
32. Rollable step: An easily movable yet stable support device that provides assistance during short maintenance periods. It is moved using a pair of wheels mounted on the side. It takes up less space than a ladder, so it can have a dedicated place next to the given technology.

Other improvements:

33. Stress management programmes: Launch stress management programmes to better manage workplace stress.
34. Rest room: A room designed for employees to take breaks and relax, where they can drink, eat, move around and rest during breaks.
35. Health checks: Conducting regular health checks to identify potential health problems in a timely manner.
36. Stretching and relaxation exercises: Providing stretching and relaxation exercises for employees to reduce muscle tension and fatigue.
37. Involvement of ergonomic consultants: Employ ergonomic consultants to obtain expert advice on improving the workplace environment.
38. Employee wellness programmes: Launch employee wellness programmes to support physical and mental health.
39. Regular ergonomic training: Organise regular ergonomic training to continuously update employees' knowledge and skills.
40. Solder fume extraction equipment: Thanks to its mobile design, it can be placed directly next to the workstation where it is needed. The extraction hose is rigid, so it can be easily positioned closest to the soldering point, which the employee can adjust to suit their needs.

PCBA handling improvements: Innovative solutions

When moving PCBA (Printed Circuit Board Assemblies) and other components, a number of ergonomic improvements can be made to improve worker health and safety. Here are some additional suggestions for moving printed circuit boards:

41. Mandatory handles: Design mandatory grip points and handles on magazine transport trolleys.
42. Ergonomic handles: Provide ergonomic handles on trolleys and storage containers for comfortable and safe handling.
43. Lifting equipment: Use lifting equipment such as electric hoists, hydraulic hoists or lifting tables to facilitate the lifting and stacking of heavy objects and PCB packages.
44. Sensors and monitors: Use sensors and monitors to monitor workers’ posture and movements in order to identify problems in a timely manner.

45. Robot magazine mover: Just like the magazine mover assistant, the goal is to handle magazines at the unloaders and loaders. In this case, since robots move the magazines, there is no need for workers to be present or to use their strength. For this, the robot also needs a conveyor belt, and the magazine unloaders and loaders must also have a constant height, and the magazine must also be loaded and unloaded using conveyor belts. Incidentally, it is advisable to set up the robot's loading station near the work area it serves.
46. Hydraulic manual pallet jack: The difference compared to hydraulic manual pallet jacks is that the height of the pallet jack can be adjusted over a wide range up to ~800 mm. This allows, under normal use, the materials to be lifted to a position where the worker can work ergonomically while standing next to the destination. This may be necessary, for example, at PCB dismantling, component dismantling and preparation stations. The stability of the structure is increased by the fact that, after lifting to a certain height, the fixed feet lift the "frog", thus securing its position. Before purchasing, it is worth considering that in confined spaces where there is no designated area for the scissor lift, it cannot be used in the long term.
47. Soldering aid JIG: During soldering, the worker can adjust the product support JIG to several positions to find the most favourable position for soldering. A custom clamping mechanism or a lever clamp can be designed. Larger components on the product may be damaged if they are not placed perfectly gently on the workstation, or may even be damaged by their own weight. These potential errors can be avoided by using a soldering jig.
48. Loading jigs: These facilitate the positioning of PCBs and provide a POKA-YOKE solution for loading into magazines, for example. The worker can reduce the concentration required to perform the operation, as the loading jig ensures that the semi-finished product is loaded into the correct divisions.

6. Summary

Based on the experience gained during our research, we recognised the importance of ergonomics in manufacturing processes. During our surveys at the electronics manufacturing company, we encountered numerous ergonomic challenges, the resolution of which had a significant impact on productivity and employee well-being. As a result of our work, we were able to collect and systematise the ergonomic improvements that had already been implemented and identify opportunities for future development. Based on this information, we intend to make recommendations to other companies dealing with similar products. The introduction and application of ergonomic improvements is therefore crucial for modern workplaces and contributes to the long-term success and sustainability of companies.

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