Workplace redesign in the computer-aided technological sewing process

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In the real manufacturing process the technological operation of sewing trousers side seams was recorded using a video system. Using modern methods of industrial engineering the structure of technological operation, workload (OADM) and share of unsuitable working postures (OWAS) were determined. It was found that at the existing workplace the unfavorable relationship of man-machine-environment leads to a high degree of workload caused by the forced position of spine and head, increased abdominal pressure, and reduction in visual skills and motor skills. Using the ERGOPlan software a redesign of the existing workplace was performed, and according to the anthropometric proportions of workers seating height, height of the machine work surface, working methods were determined, and using the method of predetermined times (MTM) the optimal working method with associated time norms was determined. Dynamic and static simulation of performing the technological operation at the redesigned workplace shows that the work is done in an ergonomically favorable posture with considerably reducing workload, which results in increasing workplace productivity while reducing fatigue.
Key words: *technological sewing operation, workplace design, computer-aided analysis of workplace*

1. Introduction

In the garment manufacturing processes the technological sewing operation is the most important phase and also dominantly present on average to 70 % of the total production time of a garment while the technological operations of cutting and finishing garments are significantly less present (about 30 %). Investigations of the structure of daily working hours in a single working step of sewing indicate that 20-30 % of the time is spent for machine-hand sewing sub-operations, 60-70 % of the time is spent for support-hand sub-operations, while about 10 % of the time is spent on unproductive work (personal hygiene, planned and unplanned losses of time and lack of discipline). According to the organization of the work process technological sewing operations belong to the so-called *stable workplaces of closed type with steady performance* where an operator performs technical operations of approximately similar characteristics. This workplace allows a higher degree of technical division of labor, specialization and shorter training time, so it achieves a higher degree of the efficiency of machines and devices, better work piece transport through a set of workplaces, reduction of production cycle and increase in the

production capacity of each workplace, production lines and the system [1].
In the technological sewing process work is done most often in a sitting position, whereby the worker during sewing uses the trunk and upper limbs to perform machine-hand and auxiliary technological sub-operations, and the feet to achieve the required stitch speed of the sewing machine in machine-hand sewing sub-operations. Because of the physical and mechanical properties of the work piece, careful handling is necessary which requires extremely good motor skills that are reflected in the mobility of the fingers, hands, arms and feet, and their concerted action and good tactile sensitivity. Machine-hand sewing sub-operation and guiding the work piece is performed within the central visual field with a high degree of vision focus, which significantly burdens the visual system and reduces the level of concentration required for accurately guiding the work piece._In technological sewing processes it often happens that because of the need of dynamic work forced postures of the body and head, non-physiological sitting, isometric loading of the lower limbs and a substantial load of arms and legs result [2].
To achieve successful operation and high productivity in the technological sewing process, it is necessary to achieve the harmony of the relationship between worker-machine-environment, which is achieved by optimal workplace design based on ergonomic principles, and by developing a favorable working method with corresponding time norms that will enable a more favorable structure of the technological operation by increasing the degree of machine efficiency and hourly production and reducing psycho-physical workload. Working posture should allow good movement of arms and legs, ergonomically favorable arrangement of work and visual zones and stable body posture while workers perform their work process [3].

2. Ergonomic considerations of sitting position

In the technological sewing process various factors, depending on garment structure, production organization, type and equipment of the workplace and working method affect workplace design. The purpose of workplace design is to adapt working methods and means of work in order to mitigate and reduce stress and fatigue during performance of the work process, to increase production quality of the garment, and to reduce production costs and production time [4]. To design workplaces successfully, it is important to apply technological and technical knowledge in the field of clothing engineering and technology. Industrial engineering methods are used to determine the level of success of the working method, and ergonomic studies are used to design space and to arrange the equipment and means of work at the workplace. Workplace design is based on the adaptation of the workplace to the anthropometric measurements of the worker with potential reach zones and necessary vision focus and arrangement of visual fields (Fig.1) which allows a faultless performance of the technological operation in a work posture which requires less consumption of body energy, and the structure of the technological operation provides a natural and normal rhythm of work with rhythmic breathing and relaxation of muscles of the chest and abdomen.
Reduced workload and efficient performance of a work task are achieved if the workplace is [5, 6]:

- adapted to the worker's body and mobility of the muscular system by its design and dimensions,
- designed in such a way that the worker works in a working posture which requires minimal static and dynamic load and that he uses muscle groups of lower level,

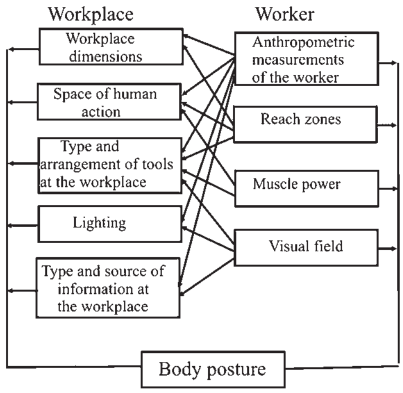


Fig.1 Interaction of workplace and worker on body posture at work

- equipped with means of work adapted to the physiological and psychological characteristics of the worker's body.

Working posture should allow good mobility of the extremities, ergonomically favorable arrangement of work and visual zones and balanced position during the work process. In the technological sewing process sitting working posture is most present; a correct and physiologically correct sitting position reduces fatigue at work and spine load, and a suitable sitting position considerably contributes to increasing concentration and work efficiency. This includes the adjustment of sitting height, height and work surface size of means of work, pedal position, and the distance of the seat from the edge of the work surface to the anthropometric measurements of the female worker who works at a workplace [7].
Poorly designed workplace causes inconvenient sitting, and there is a considerable load of the lumbar and cervical vertebrae, which is reflected in an increased pressure on cartilaginous rings, and a disease can occur (lumbar ischialgia) or professional degenerative changes (scoliosis, kyphosis).
Long-lasting load of individual groups of muscles (neck, paravertebral, gluteus) caused by sitting leads to fatigue and weakening motor functions. In sitting position due to constant static pressure on internal organs mi-

croorganisms causing infections and urinary tract inflammation (cystitis, ureatitis) are created in the abdominal cavity. With a poorly designed workplace or a working method, the worker sits on the edge of the seat, which is only a temporary relief, and it causes an increased anterior flexion of the cervical vertebrae and the head, causing neck and shoulder stiffness, headache, high eye strain, fatigue and reduced necessary attention. In addition, due to the unsuitable sitting position the normal function of the respiratory system is reduced, and the reduced level of blood oxygenation also causes headaches [8].

In the technological sewing processes the middle and anterior sitting posture interchange because of necessary dynamic work, and the frequency of the trunk movement depends on the type and characteristic of the technological operation. In the anterior sitting posture load of the disc of the spine is not evenly distributed, so the disc moves forward, while in the middle sitting posture it is uniformly distributed.

The seat is one of the most important elements of the workplace in the technological sewing process; thus, ergonomically suitable sitting, which satisfies convenient comfort and mobility, necessary degree of trunk balance and freedom of movement are essential when performing dynamic movements. Stable working posture and the required degree of balance is achieved by foot and backrest. The contact area between the seat and the body is on average 26 cm^2 to which about 75 % of the total mass of the body is transferred, whereby on the surface of the seat pane a specific pressure of $5.9 \cdot 10^5$ to $7.0 \cdot 10^5$ Pa is achieved. In the technological process of the garment industry industrial seats DIN 45551 and 66233 are most commonly used; they are adaptable to the anatomical shape of the human body, and the curve of the backrest supports the lumbar region of the spine (L_1 - L_5) [9,10].

Properties of the seat and backrest as well as other factors such as perception, relaxation, general wellbeing of the body, and degree of fatigue, biomechanical conditions, and stress and blood circulation are essential for comfortable sitting. The feeling of comfort is associated with the parameters such as pressure, temperature and relative humidity at the contact point of the body with the surface. Mechanical comfort is defined as part of the overall comfort which depends on the distribution of contact pressure over the human body in contact with the seat. Contact pressure, its distribution and duration of action are the principal factors of mechanical comfort. According to the theoretical model there are different factors of comfort and discomfort in sitting. They can be divided into three levels: system, seat, man. Physical characteristics of the working seat like shape, softness, environment (type of work task) load the body and joints of sitting persons with different forces and pressures. Internal powers reducing muscle changes in internal forces, increased pressure on intervertebral discs including nerves and circulation, as well as higher body temperature causing further chemical, physiological and biomechanical reactions disturb external load, Fig.2 [11].

The underlying principles in the design and construction of seats require providing the proper distribution of human body mass, the possibility to adjust sitting height, depth and availability of space, the possibility to stabilize body posture, but also mobility, visibility of a certain space and sitting comfort.

3. Experimental part

The experimental part of the technological operation of sewing trousers side seam performed on a special MAUSER SPEZIAL 9652-13M/14-363-W2X4 Overlock Sewing Machine included:

- video recording in the real manufacturing process,
- analyzing the existing workplace (structure and duration of performing the technological operation, and determining workload using OWAS and OADM methods),
- redesigning the workplace using the ERGOPlan software package,
- redesigning the existing workplace and developing a new optimum work method with corresponding normal times : MTM (Motion Timestudy Measurement) and RAV-method (method of determining machine-hand times of the technological sub-operation of sewing flat seams) in order to rationalize work

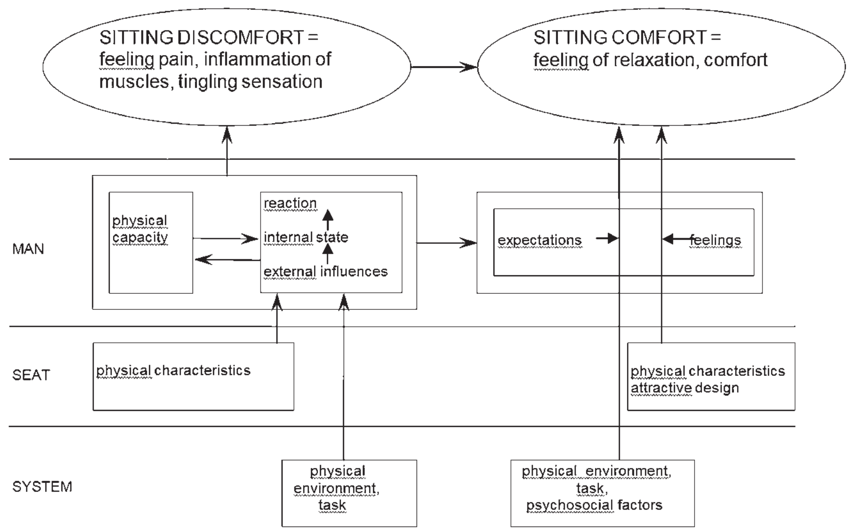


Fig.2 Theoretical model of comfort and discomfort and their factors at the level of man, seat and system

process, to reduce level of workload and time execution.

3.1. Measuring equipment and measuring methods

The technological operation of sewing the trousers side seam was recorded using the video system of Pounje, Hrvatska Kostajnica. To record the technological sewing operation, a video camera SONY DCR-HC42E with time generator with an accuracy of ± 0.1 s was used. The video camera was placed in such a way that the workplace was present in the field of vision as body plan which allowed recording with maximum zones of dynamic movements in performing the work process. The video recording was used to test the applied work method, determination of time norms and working postures of the female worker in performing the technological operation. DVD recorder SONY SLV D970P, personal computer and color printer were used for processing video recording. The video can be slowed down (1/4, 1/8) or completely stopped for a detailed analysis of the performance of movements and corresponding posture. A PC Pentium 4, 2.8 GHz, 1024 MB RAM with the installed Microsoft Windows 2000 operating system was used. The computer has a graphics card NVIDIA Ge Force FX5200 and supports a resolution of 1280 x 1024 Pix and has 32 bit color. To analyze the video recording, the computer program Adobe Premier 5 and Corel Draw 11 was used. Computer processing of video recordings enables the analysis of the video recording "frame to frame" in Adobe Premier 5, where the time of performing particular technological sub-operations in the structure of the technological operation was determined. Furthermore, typical static frames were transferred to the computer program Corel Draw 11, where the angle of spine curvature and head was determined using Angular Dimension Tool.

The workplace where the technological operation was performed was photographed with a digital camera Canon EOS 350D whose image quality is 8 MPix. The camera has 10x optical zoom, 4x digital zoom, 1.8 "LCD color monitor. Supported formats were JPEG and RAW. Computer program ERGOPlan or module ERGOMas and module ERGO-Man were used to appropriately redesign the workplace with the corresponding method for the technological operation. Tests were performed at the Faculty of Mechanical Engineering, University of Maribor, Production System Design Laboratory.

The following parameters were measured in order to define the state of the work environment:

a) temperature and relative humidity (using a thermo-hygrometer, model YF-180) with a temperature measurement accuracy of ± 0,5 % + 1 °C ranged from 0 to 60 ° C, and a relative humidity measurement accuracy of ± 3 % ranged from 10 to 70 %, and ± 4 % ranged from 10 to 95 %, respectively,
b) sound level (using a *Tenmars* digital sound level meter) measuring sound strength ranged from 30 to 130 dB, frequency from 31.5 Hz to 8 kHz with an accuracy of ± 1,5 %,
c) illumination (using a digital light level meter, model YF-170), which can measure the light ranged from 200 to 20,000 lx) and
d) air flow (using the anemometer EA - 3010) with the possibility to measure in the range of 0.2 and 30 ms^{-1} with an accuracy of ± 5 %).

In order to determine **an optimal working method with corresponding normal times**, the MTM system was used. This system allows analytical subdividing technological operations to the level of basic movements, and corresponding variables according to movement length, accuracy and dynamics of execution, necessary visual and muscular controls and possibilities of coordinated work with combined and simultaneous movements. By breaking down the technological operation to the level of basic movements it is possible to find out optimum and cost-effective work methods and to determine normal time of performing technological operations [12, 13].

In order to redesign a workplace using the MTM system, it is necessary to define a logical set of movements according to the variable of basic movements (length and type of movements), accuracy of execution and necessary visual control by which the optimum method of performing a sub-operation is determined. The MTM system is used to design workplaces and production systems [14].

In order to determine **normal machine-hand times of the technological sub-operation of sewing** straight seams, the RAV software package as a mathematical model obtained by systematic research of process sewing parameters using the patented measuring equipment for measuring process parameters (MMPP) developed at the Department of Clothing Technology of the Faculty of Textile Technology of the University of Zagreb was used [15]. The established mathematical model determines the dependence of normal times of machine-hand suboperatios on nominal sewing machine stitching speed (v_n = 1000-7000 rpm), number of stitches in a seam (B_u = 10-300), seam length, and sewing machine type. The model also incorporates the correction factor for the sewing machine type which is caused by the complexity of using the machine, the complexity of the machine mechanism and inertial characteristics of a particular group of sewing machines (K_1). The complete established mathematical model of the RAV method for determining machine-hand technological sub-operations is as follows:

$$t_{ar} = \{B_u \cdot [0,227 - 0,025 \cdot \ln (v_n)] + 0,334\} \cdot K_1 \quad (1)$$

For the mathematical model of the RAV method the corresponding computer program to calculate the times of machine-hand technological sewing sub-operations was developed, using the default parameters of nominal sewing machine stitching speed, number of stitches in a seam and the correction factor for the sewing machine type. The program calculates the normal time of a machine-hand technological sub-operation in sewing, expressed, depending on the need, in seconds, TMU, minutes and hours[16-18].

To determine working body posture, the OWACO (Ovaco Working Posture Analysis System) was used which is based on the analysis and share of working postures of spine, upper limbs, hand, lower limbs and head when performing the work process. Depending on the portion of time of certain body working postures, the need for redesigning the workplace and working methods are emphasized. This method allows determining unfavorable working postures of individual body parts at work, the cause of their occurrence, and this analysis makes it possible to design or redesign the workplace so that the worker works in a working posture, which requires a minimum of static and dynamic load [19].

The OADM method (workplace evaluation analysis) developed by J. Sušnik et al. makes it possible to detect deficiencies and failures that occurred when designing a workplace, as well as shortcomings in the organization of the production system, and provides an analysis and evaluation of the workplace with respect to static , dynamic and thermal loads, necessary visual control and state of the working environment [20, 21].

The ERGOPlan software package allows the virtual simulation of the continuous workflow of the complete process using an integrated module for developing the structure of a technological operation, workplace design, ergonomic workplace analysis, execution-time analysis, cost analysis and analysis of workload.

3.1.1. Analysis of the structure and time of performing the technological operation

The technological operation of sewing a side seam for girls' trousers size 15 whose cut length amounts to 95 cm with an ease of 4 cm is performed on a special MAUSER SPEZIAL 9652-131M/14-363-W2X4 Overlock Sewing Machine. The machine sews chain stitch type 515 with four sewing threads and two needles and a specific stitch density of 5 cm^{-1}. Nominal stitching speed of the sewing machine is 6,000 rpm. The machine has two pedals of which one pedal is used to lift or to lower the presser foot, and the other one is used to guide the sewing process. The operator recorded performs the sewing operation in 5 seam segments, Fig.3, with a total seam length of 100 cm.

According to the existing working method a bundle of back trousers parts is on the left side of the work surface of the sewing machine, and a bundle of front trousers parts lies on the operator's lap causing non-ergonomic sitting on the edge of the chair seat, often changing the sitting position with a distinct anterior flexion of the head and trunk. Balanced position can be established only using the feet.

The technological operation of sewing the trousers side seam was recorded using a video system and contains 31 consecutive executions. The coefficient of workplace stabilization (K_s) with a 95 % probability indicates that the video recording of performing the technological operation is big enough and suitable for further analysis.

Fig.4 shows the ground-plan representation of the existing workplace for the technological operation of sewing the trousers side seam.

By analyzing the operator's work capabilities according to subjective perception a degree of proficiency K_p = 1.0 was determined. In the manufacturing plant an average temperature of 28.4 °C and a relative humidity of 57.7 % with a weak air flow were measured. According to certain parameters of the working environment the coefficient of environment action K_a = 1.55, and the associated fatigue coefficient K_n = 0.11 were determined.

Table 1 shows the structure of the technological operation of sewing the trousers side seam with corresponding time norms: basic time (t_0), normal time (t_n) and real time (t_s).

Temporal values for putting together and positioning the work piece are short, and therefore they are in the analysis of the video recording connected with the technological sub-operation of taking the work piece. Due to the short duration of the execution the technological sub-operation of thread cutting off and the technological sub-operation of laying off the previous trousers were unified with the technological sub-operation of aligning the trousers. The total normal time of performing the technological operation is 35.0 s, the duration of auxiliary hand technological sub-

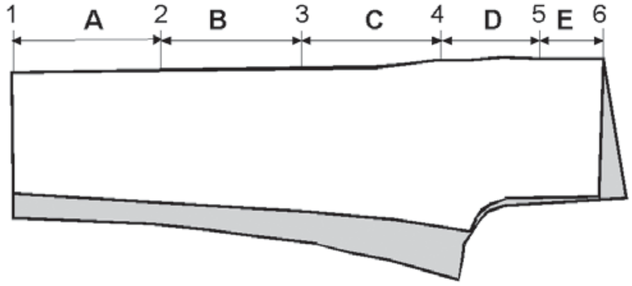


Fig.3 Sketch of developing the technological operation of sewing the trousers side seam with control points

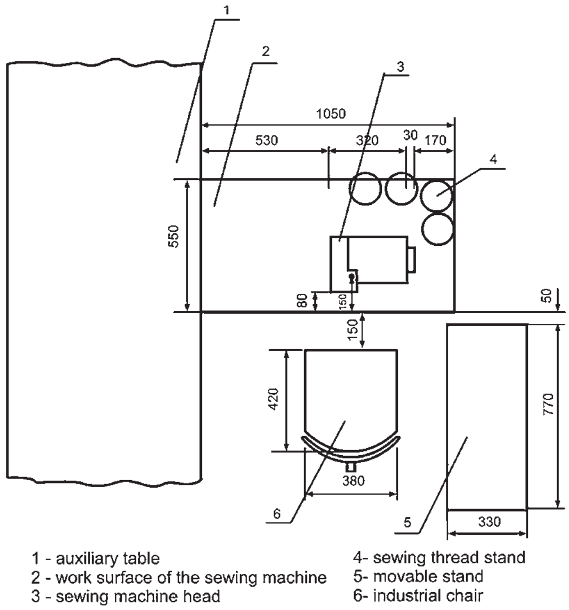


Fig.4 Ground plan representation of the workplace for the technological operation of sewing the trousers side seam

operations is 23.9 s or 68.3 %, while the duration of auxiliary hand technological operations is 11.1 and31.7 % respectively.

Based on the data obtained by analyzing the video recordings and by correcting with the fatigue coefficient K_n and the coefficient of environment action K_a the manufacturing time is 41.0 s with an ideal hourly production of 87 Ch^{-1}.

3.1.2. Analysis of workload with the OWAS method

For the analysis of workload in the technological operation of sewing the trousers side seam the OWAS method was used, whereby 825 records of individual body postures was collected. Based on them the share and duration of each working posture within the effective daily working hours was calculated and compared with the browser for the evaluation of body pasture. Fig.5 shows the permissible percentage of presence of each working posture within the effective daily working hours and the results obtained by analyzing the workload of the worker when performing the technological operation.

For the technological sewing operation investigated the duration of the shift with prescribed daily rest break and time loss of 10 % (due to organizational loss and personal needs) effective daily working time is 405 min.

Tab.2 shows the results obtained by the OWAS method.

Fig.6 shows boundary working postures of the worker when performing the technological operation of sewing the trousers side seam with kinematic chains. A female worker of a shorter anthropometric measurement (157 cm) occupies the workplace. Due to the unmatched height of the work surface and the height of the chair the worker sits in an unfavorable working posture. The consequence is a negative angle of the joint system trunk-upper leg that is less than 90°; this is the reason why the worker works with a large inclination of the head and trunk (>15°) most of the working

Tab.1 Structure of the technological operation of sewing the trousers side seam by technological sub-operations with associated time norms

No. of technological sub-operation	Description of the technological sub-operation	Type of the technological sub-operation	Marks of a break point	End points of the segment	t_0 [s]	t_n [s]	t_s [s]
1	taking the front trouser part	$(t_p)_r$	-	-	5.2	5.2	6.1
2	taking the back trousers part and putting together, positioning	$(t_p)_r$	-	-	5.2	5.2	6.0
3	machine-hand sewing the segment A	$(t_t)_{ar}$	-	1-2	3.4	3.4	4.1
4	thread cutting off, laying off the previous trousers, aligning	$(t_p)_r$	2	-	5.4	5.4	6.3
5	machine-hand sewing the segment B	$(t_t)_{ar}$	-	2-3	2.0	2.0	2.3
6	manual aligning	$(t_p)_r$	3	-	2.7	2.7	3.2
7	machine-hand sewing the segment C	$(t_t)_{ar}$	-	3-4	2.0	2.0	2.3
8	manual aligning	$(t_p)_r$	4	-	2.8	2.8	3.3
9	machine-hand sewing the segment D	$(t_t)_{ar}$	-	4-5	2.1	2.1	2.5
10	manual aligning	$(t_p)_r$	5	-	2.6	2.6	3.0
11	machine-hand sewing the segment E	$(t_t)_{ar}$	-	5-6	1.6	1.6	1.9
Σ					35.0	35.0	41.0

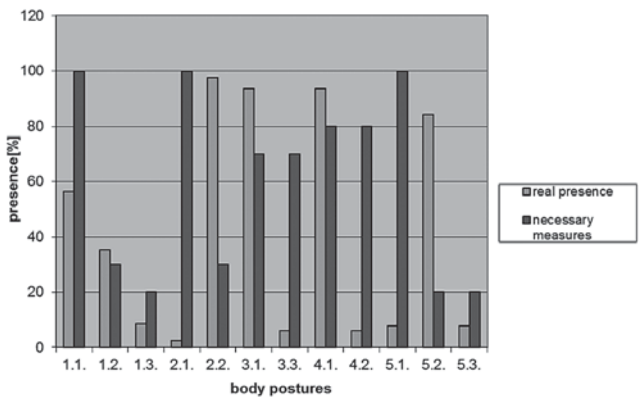
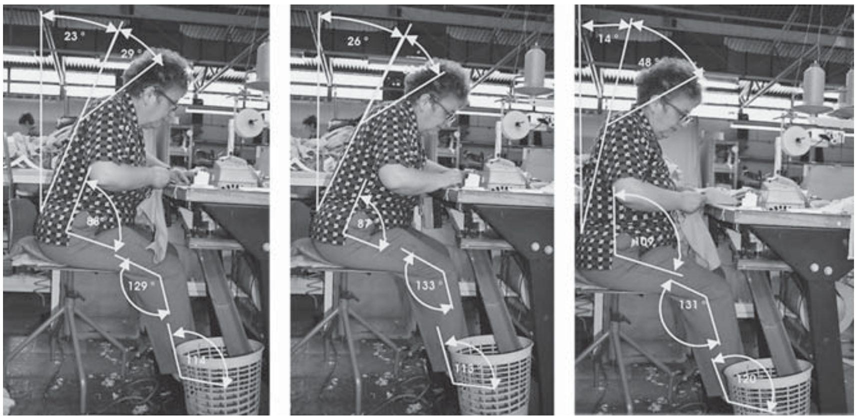


Fig.5 Measurement histogram according to the OWAS method at the work place of sewing the trousers side seam



Workpiece positioning | Machine-hand sewing of a workpiece | Workpiece alignment

Fig.6 Boundary working posture at the workplace for sewing the trousers side seam with kinematic chains

time trying to reduce the distance of the eyes from the work piece in the technological sub-operation of positioning and machine-hand sewing.

3.1.3. Analysis of workload with the OADM method

By using the OADM method or a questionnaire with 216 descriptions of possible states in the workplace, an analysis and gradin of the workplace was performed where the technological operation of sewing the trousers side seam was performed. The grade encompasses the characteristics of an operating system (work piece, means of work, workplace, worker, working environment), the work task itself (complexity of method of work), possible load (necessary motor skills, concentration, qualification), and health safety (risk of injury and occupational diseases). Table 3 provides an overview of worker load for the technological operation with the associated grade of individual characteristics.

Work parameters are denoted with a code number and alphabetic character. Alphabetic characters indicate the criterion according to which grading is performed. Each parameter is graded by one criterion, so-called key. The criteria are divided into:

- alternative (A) - grade of the presence of some parameters,
- significance (V) - grade of significance in contrast to other states at the workplace,
- intensity (I) - grade of the intensity of a parameter,
- duration (T) - grade of the temporal duration of a parameter,
- frequency (p) - grade of the repetitiveness of a parameter at the workplace,
- parameters (K) - grade is different and given with parameter description.

Criteria of significance, intensity, duration, frequency and characteristics have a scale of six grades (0-5) while the alternative has only two (0, 1).

On the basis of the grade of worker load using the OADM method at the existing workplace the data obtained indicate a high degree of motor coordination of body, arms and legs, whereby muscle load and forced positions of the body and head as a consequence of an unfavorable sitting position and the discrepancy of workplace dimensions as well as an inadequate method of work result. The technological operation is performed on a sewing machine where a high degree of work repetitiveness is present, and the worker handles the subject of work more than 2/3 of working time; due to the necessary precision of performing the technological operation

Tab.2 Unfavorable working postures and their temporal values according to the OWAS method

Joint system	Achieved angle or position	Effective time [%]	Effective time [min]
anterior spinal flexion (1.2.)	> 15^0	35.1	142.2
anterior head flexion (5.2.)	>30^0	84.1	341.0
upper arms (2.2.)	away from the body	97.6	395.3
hand and fingers (3.1.)	precision work	93.6	379.1
sitting (4.1.)	exchange between anterior and posterior postures	100.0	405.0

Tab.3 Workload according to the OADM method for the technological operation of sewing the trousers side seam

Code	Worker load	Grade
103,105,108	worker continuously handles the subject of work more than 2/3 of working time	T/4
122	worker continuously handles the means of work more than 2/3 of working time	T/4
139,140,141	use of fingers, hands and feet more than 2/3 of working time	P/4
148, 151	desk and pedal cannot be adjusted	K/2
149	height of the chair can be adjusted	K/2
152,153	check lighting and noise at the workplace	K/3
157	check climatic parameters at the workplace	K/3
182	connection of the workplace with the continuity of the work process	K/5
189	division of labor present	K/4
191	great responsibility at the workplace	I/4
216	female worker puts together cut parts	V/5
249	work is performed on a sewing machine with repetitive work of the hands	K/2
250,251	visual acuity necessary	K/3
253	eye accommodation necessary	P/4
259	color recognition necessary	K/3
260	precise assembly of the work piece necessary	K/4
274,286,288,294	correct contour tracking necessary, and the worker should be calm, self-critical, motivated and persevering at work	V/3
311	non-physiological sitting present	T/5
318	forced position of the neck and head	P/4
321	isometric foot load	P/4
328,329,330,331,334	load of fingers, hands and feet present	P/3
342,343,344	important is the simultaneous work of hands with finger dexterity and oculomotor coordination	I/3
357,364	spine and eye diseases possible	K3

it is necessary for the worker to possess good sensory abilities of the sensory organs of vision which refer to visual acuity such as the ability to perceive details and parts. High dynamism of movements performed at the workplace requires the ability of accommodation and adaptation of the eye. By analyzing the workplace, it has been found that it is necessary to perform additional measurements from the standpoint of technological problems, time study, and to verify the state of the working environment and the impact of non- physiological sitting on work load [22].

3.1.4. Workplace redesign

Investigations (analysis) of the technological operation of sewing the trousers side seam indicate the need to redesign workplaces and to find out a more favorable method of work which could reduce the degree of load due to unfavorable working postures. For this purpose the workplace was redesigned using the ERGOPlan software package and its modules ERGOMas and ERGOMan. According to the anthropometric measurements of the worker (body height 157 cm) and work piece size (front and back trousers part) the computer method ERGOMan was used to determine the height of the work seat of 450 mm including pedal height (5 cm) and footrest for lightweight shoes (2 cm), work surface height of the sewing machine (740 mm); due to the work piece size it was necessary to increase the work surface of the sewing machine on the left side to 1250 x 850 mm. In this way a comfortable sitting position was achieved, and the line of the viewing angle towards the central sewing work zone is less than 40 ° with respect to the standard line of viewing from a distance of 350-400 mm. This redesigned workplace makes it possible that both work pieces are placed on the machine work surface, and a movable stand on the right side is used for laying off the work piece.

Fig.7 shows the redesigned workplace for the technological operation of sewing the trousers side seam which was obtained using the module ERGOMan with a 3D (a), ground plane (b) and side view (c) representation

Fig.8 shows a detailed ground-plan representation of the workplace for the technological operation of sewing the trousers side seam with reach zones and horizontal angles of vision.

After redesigning the work place a statistical analysis (initial working posture) was performed; this verified if the height and the size of the work surface and sitting height match the body height of the worker. It was found that the worker takes the proper sitting working posture, Fig.9a, and that in the work place the machine, work surface and work pieces are located within the zone of normal arm reach, Fig.9b.

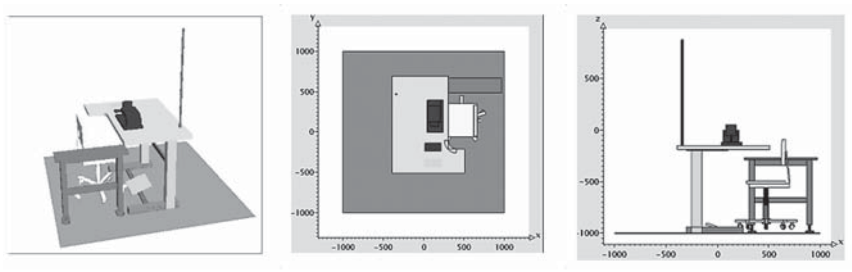


Fig.7 Redesigned workplace for the technological operation of sewing the trousers side seam: a) 3D representation, b) ground-plan representation and c) side view representation

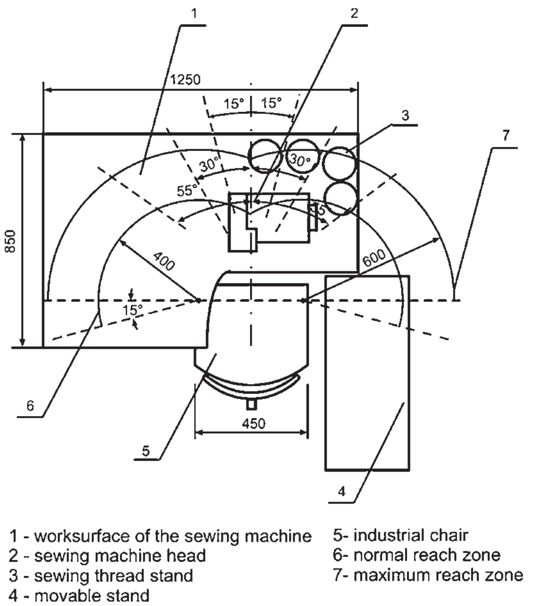


Fig.8 Proposal of redesigning the workplace with reach zones and horizontal angles of vision for the technological operation of sewing the trousers side seam

The workplace was dynamically analyzed after the performed static analysis of the workplace or verifying the compliance of the workplace dimensions with the anthropometric measurements of the worker. According to the ground plan of the redesigned workplace (Fig.8) and static analysis of the working posture (Fig.10) a design of the optimum method of work using the MTM system was performed:

- taking work pieces and transporting into the work zone
- positioning the work pieces
- overlocking the seam
- thread trimming
- laying off the work piece.

Bundles of work pieces are located on the left side of the work surface, and work pieces are taken from the bundles using a logical set of basic movements as a standard set: *taking a work piece with both hands from one and then from the other bundle and transporting into the central work zone* [23].

Since work pieces are large in size (front and back trousers parts), an additional control of the set of movements that can be accomplished by raising the work piece prior to transporting and by changing in right hand grip (RL1/R30E/G1A) is necessary. Thus, the controlled grasp of the work piece with both hands is accomplished where the distance between the grips ranges from 10 to 30 cm. The logical set of movements for this kind of taking is accomplished by simultaneous movements of reaching with both arms to bundle I, taking the work piece with both hands and transporting it to bundle II, precise putting together (with a tolerance zone from 0.4 to 1.6 mm) and mutual transporting into the central sewing work zone [24].

The positioning of the work piece under the needle of the sewing machine is performed by transporting mutually assembled parts to the pressure foot, their precise putting under the machine needle and lowering the pressure foot.

The sewing sub-operation is performed with the simultaneous control of keeping the left and right arm and guiding both parts together in the course of sewing.

At the redesigned workplace sewing side seam can be performed in three segments: the first segment ranges from trousers length to knee height (35 cm), the second segment ranges from knee height to waist height (35 cm) and the third segment ranges from hip height to waist line (30 cm), Fig.10. The corresponding normal

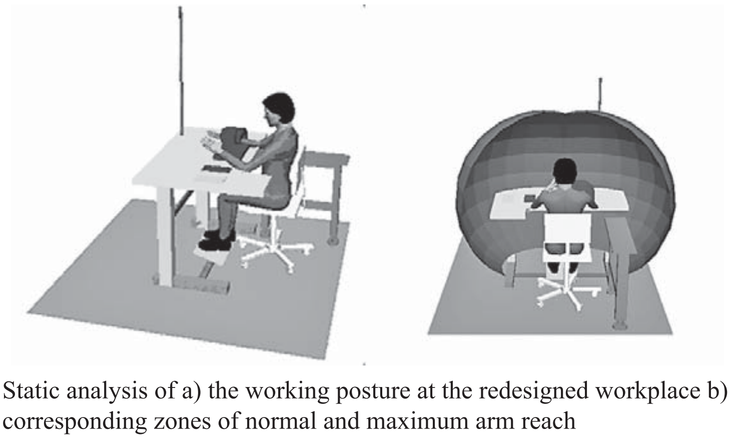


Fig.9 Static analysis of a) the working posture at the redesigned workplace b) with corresponding zones of normal and maximum arm reach

Tab.4 Presentation of the logical set of basic movements developed according to the MTM system when designing an optimum method of work for the technological operation of sewing the trousers side seam

MTM analysis of work					
Technological operation: Sewing the trousers side seam					
No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1.	**Taking, putting together, transportation**				
1.1	Reach for bundle I	mR60B	18.5		
1.2	Grasp the work piece	G5/G2	5.6		
1.3	Lift the work piece	M30B	13.3	(mR40Am)	Reach for work piece I
1.4			0.0	G5	Grasp work piece I
1.5			11.7	mR30E	Reach the arm along the edge
1.6			2.0	G1A	Grasp the edge of work piece I
1.7	Transport work piece I to bundle II	M20C	11.7	(M20B)	Transport work piece I to bundle II
1.8	Put on point I	P1SE	5.6		
1.9	Grasp the work piece together	RL1/R4B/G2	11.0		
1.10			14.8	RL1/R30E/G1A	Change the grip
1.11			5.8	M6C	Transport the work piece to point II
1.12			5.6	P1SE	Put together on point II
1.13			11.0	RL1/R4B/G2	Grasp the work piece together
1.14	Transport the wok piece into the central sewing work zone	M60B	28.3	M60B	Transport the work piece into the central sewing work zone
2.	**Positioning**				
2.1	Transport towards the needle i	(M4C)	8.5	FM	Lift the pressure foot
2.2	Precise positioning under the needle	P1SE	5.6		
2.3			8.5	FM	Lower the pressure foot
3.	**Sewing (3 segments)**				
3.1	Activate the pedal	FM	8.5		
3.2	Sew segment I (35 cm)	t_{ar}	77.8		
3.3	Deactivate the pedal	FM	8.5	(RL1)	Let off the work piece
3.4			14.8	mR40E/G1A	Change the grip
3.5			11.4	M6C/P1SE	Precisely put on point II
3.6	Activate the pedal	FM	8.5		
3.7	Sew segment II (35 cm)	t_{ar}	77.8		
3.8	Deactivate the pedal	FM	8.5	(RL1)	Let off the work piece
3.9			14.8	mR40E/G1A	Change of the grip
3.10			11.4	M6C/P1SE	Precisely put on point II
3.11	Activate the pedal	FM	8.5		
3.12	Sew segment III (30 cm)	t_{ar}	66.7		
3.13	Deactivate the pedal	FM	8.5		
4.	**Cut off the thread with the thread trimmer**				
4.1	Transport to the mechanism and cut off	M10C/P1SE	13.5	(M10C/P1SE)	Transport to the mechanism and cut off
5.	**Laying off the work piece on the movable stand**				
5.1	Transport the work piece	$M120B_{CD}$	25.2	(RL1/R30E/ G1A)	Change of the grip
5.2	Let off the work piece	RL1	2.0	RL1	
5.3	Return to balanced position	R50 Em	15.4	R50 Em	Return to balanced position
	Σ		549.3 TMU=19.8 s		

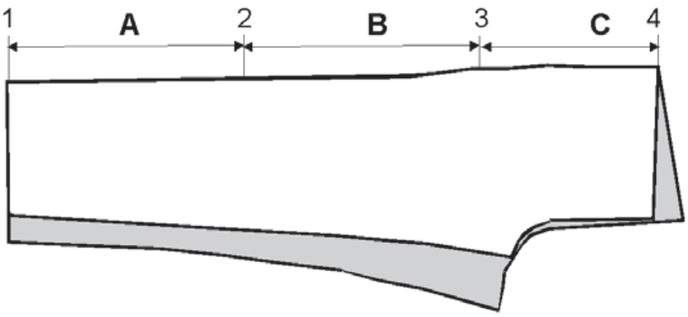


Fig.10 Sketch of developing the technological operation of sewing the trousers side seam with control points at the redesigned workplace

times of machine-hand sub-operations for each segment are determined by the RAV method.

The thread is cut off at the end of the technological sub-operation.

The work piece is laid off at the end of the technological operation, It is laid off on the movable stand on the right side of the designed workplace 10 to 15 cm under the work surface. After sewing the worker moves from anterior sitting position to middle sitting position creating an elevated dynamic zone of activity which enables laying off a bigger size work piece on the movable stand using simultaneous movements of both arms within normal reach.

Tab.4 shows a logical set of basic movements developed according to the MTM method when designing an optimum method of work for the technological operation of sewing the trousers side seam.

By redesigning the workplace and using the analytical method with the MTM system the normal time of execution amounts to 19.8 s, and processing time is 23.2 s.

According to the designed optimal method of work specified by the MTM system the logical set of movements using the computer module ERGOMan simulating the performance of technological operations at the redesigned workplace was determined. Fig.11 shows the performance of the technological operation of sewing the trousers side seam according to the technological sub-operations.

The technological sub-operation of taking the back trouser leg part and putting together is shown as one technological sub-operation because it is performed in the same working posture. Likewise, the technological sub-operation of positioning and machine-hand sewing was also unified. The OWAS analysis of each working posture is presented for each technological sub-operation. The simulation of performing the technological operation indicates that the worker works in a favorable working posture with a significantly reduced workload (green OWAS) with the tolerant presence (less than 10 %) of unfavorable working postures (1.2, 2.2, 3.1, 4.1 and 5.2).

Based on the performed computer-aided work place redesign for the technological operation of sewing the trousers side seam, it is evident that the workplace was ergonomically more favorably designed, and a more favorable method of work was determined resulting in lower workload and fatigue.

4. Discussion and conclusion

For the technological operation of sewing the trousers side seam a video recording in real production time was performed; the existing workplace was analyzed according to the structure and time of performing the operation and work load was determined (OWAS and OADM method).

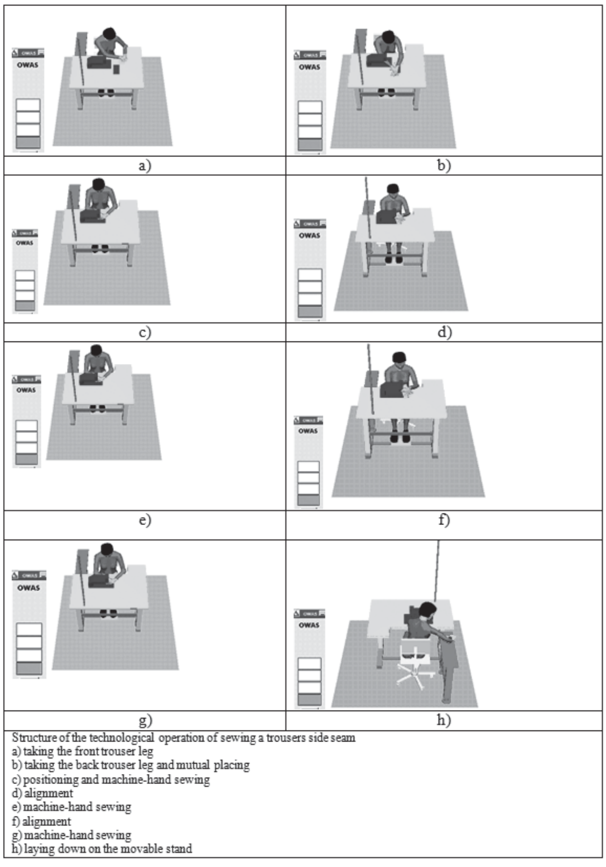


Fig.11 Simulation of the dynamic analysis of the workplace for the technological operation of sewing the trousers side seam

It was found out that the unfavorable relationship man-machine-environment causes a high level of workload as a consequence of the forced position of spine and head, increase in abdominal pressure, reduction in visual abilities and motor skills caused by inappropriate angles of the associated kinematic joint systems.

The existing workplace was not designed according to the anthropometric measurements of the worker (sitting height, work surface height, distance of the trunk from the edge of the work surface) causing non-ergonomic sitting at the seat edge, frequent change of the sitting position with pronounced anterior head and trunk flexion, and balanced position is achieved only using the feet.

According to the used method of work the technological operation of sewing the trousers side seam is performed in six auxiliary-hand sub-operations and five machine-hand sub-operations within which a 100 cm long seam is sewn in five segments (Tab. 1; Fig. 3). Normal duration of the execution of the operation amounts to 35.0 s, and processing time amounts to 41.0 s.

The results obtained by the OWAS method (Fig.5) indicate that the working posture with the anterior flexion of the spine with an angle greater than 15° (posture 1.2.) amounts to 35.1 % of working time (142.2 min), while the head in the anterior flexion position with an angle greater than 30° (posture 5.2) amounts to 84.2 % of working time (341.0 min). The mentioned position of the spine and head leads to an increased level of load in the cervical and lumbar spine causing uncomfortable working posture and a higher degree of workload.

While working at the sewing machine the worker works with her upper arms away from the body (posture 2.2) 97.6 % of working time (395.3 min), which causes elbow and shoulder load. The fingers are used for precise and exact movements of taking, grasping and guiding the work piece (posture 3.1) amounting to 93.6 % of working time (379.1 min). Unfavorable working postures (1.2, 2.2, 3.1, 4.1 and 5.2) and their significantly increased temporal value in the work process (Tab.2) indicate the need for a modification of the existing workplace.

The workplace was redesigned using the ERGOPlan software package according to the anthropometric measurements of a 157 cm tall female worker. Fig.7 and 8 show the redesigned workplace with a sitting height of 45.0 cm from the floor whereby the lower leg length is pretty high (44.3 cm) and additions for the medium pedal height (5.0 cm) and light-weight shoes (2.0 cm). Besides that, due to the work piece size it is necessary to expand the machine work surface on the left side to 1280x850 mm. This results in a comfortable sitting with optimum horizontal and vertical angles of vision, and movements are carried out within the normal reach (movements of type III). The balanced position of the trunk in sitting is achieved using the feet and the backrest.

For this kind of the workplace a new method of work using the MTM system was developed (Tab.3). It consists of 5 sub-operations, and the machine-hand sewing operation with a necessary tolerance ± 1 mm and normal reaction abilities of the worker is performed in three segments (Fig. .10). According to this work method taking work pieces and transporting into the work zone is performed with a logical set of movements as a standard: *taking a work piece with both hands from one bundle and then from the other bundle and transporting into the work zone.* According to the designed method of work normal time of performing the technological sewing operation amounts to 19.8 s, and processing time amounts to 23.2 s. By simulating the dynamic analysis of work at the so designed workplace using the module ERGOMan (Fig.11) work is done in favorable working postures, and the tolerable presence of unfavorable working postures (1.1.; 2.2. and 5.2.) is less than 10 %.

On the basis of the research conducted modern methods of industrial engineering were approached and criteria indicating the need for redesigning the existing workplace were developed.

This kind of the model including a set of procedures can be used in clothing engineering for redesigning existing workplaces or designing new workplaces already in the design phase of production systems.

The design process is based on anthropometric measurements of workers and setting up compatible man-machine relationships and optimal methods of work that will lead to increased productivity of the workplace and lower levels of worker load and fatigue.

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