Defining standard sets of motions in the technological suboperation of sewing using the MTM-System

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According to its execution structure, the technological sewing operation consists of support-hand suboperations: taking, putting together, positioning, suboperations during sewing breaks and laying off as well as the technological machine-manual suboperation of sewing. In the paper an overview of possible individual suboperations contained in the technological sewing operation and perform of the technological suboperation of sewing are given. Within the technological suboperation of sewing the methods of guiding the work piece in the sewing process, various methods of seam bar tacking, use of auxiliary devices, suboperations during sewing breaks, various methods of cutting of the thread regarding the technical equipment of the sewing machines, seam properties, and level of worker training were developed. By systematic exploration of possible work methods, their standardization and elaboration to the level of basic motions using MTM (Method Time Measurement) system, standard logic sets of basic motions have been established, which can be used to determine the optimal work method which enables the determination of real norms and the reduction of workers workload.

Key words: *technological sewing process, MTM system, basic motions, standard sets of motions, technological suboperation of sewing.*

1. Introduction

The technological process of sewing clothes depending on the type of garment requires a relatively large number of technological operations to be carried out at workplaces. According to the organization, the technological sewing process belongs to the assembly (piece) type of the work process with the linear installation of work places, and individual technological sewing operations belong to the *so-called stable workplaces* of closed type with steady performance where worker performs operations of approximately similar characteristics. This workplace allows a higher degree of use of machines and devices, better work piece transport through a production lines, reduction of production cycle and increase production capacity of each workplace, production lines and the whole production system [1].

Technological sewing operations are done usually in the sitting position at sewing machines, which have machine-manual features, where is a worker-machine relationship. This represents a closed cycle of necessary reactions to be performed whereby the worker has a key role in performing the sewing process and/or making necessary decisions [2].

Such a working system requires a high degree accuracy and coordination of motion with the required visual focus of the view in the central visual field with simultaneous guide

of sewing process using controlled foot motion to adjust the stitch rate of sewing and at the same time to control the distance of the seam line from the edge of the work piece, mutual alignment of the edges of the work piece, and the length of the joint to the end of the seam. In the technological sewing process, because of the need of dynamic work, the worker often works in forced postures of the body and head causing nonphysiological sitting, isometric loading of the lower limbs and a substantial load of arms and legs [3, 4]. In the technological sewing process, it is therefore necessary to design each workplace based on ergonomic principles and to develop a favourable work method with belonging time norms that will enable normal workload, continuous material flow in the production lines and a more favourable structure of the technological operation.

The MTM system (Methods Time Measurement) provides a clear description of work methods with required normal times of individual motions, and determines the principles based on worker with normal mental and physical abilities performs a certain sequence of motions. The MTM system consists of nine basic motions of the fingers, hands and arms, two eye motions, and ten motions of the body, legs and feet with about 400 normal times in performing basic motions, whereby a movement symbol is derived from the Basic English Terminology. According to possible performance variables (length of movement, type, case, degree of accuracy, etc.), the basic motions with the belonging normal times (t_n) are presented in the literature [5, 6]. By applying the MTM system, it is also possible to determine the possibility of coordinated perform of combined and simultaneous movements. The time unit of the MTM system is TMU (Time Measurement Unit) being 10^{-5} h (3.6×10^{-2} s) [7]. Studies of the working process with the application of the MTM system enable to find, develop and prepare optimal work methods before starting the clothing manufacture, to design manufacturing systems of the clothing technology, to chose optimally layout of equipment and machinery, to train workers according to the established optimal work method, to determine the degree of use of production capacities and to monitor the execution of production plans, to rationalize the existing procedures and work methods, and to identify the actual and real norms regarding the composition of the personnel and installed equipment [8, 9].

2. Principles of creating work methods

The technological process of sewing consists of a number of technological operations depending on type, model and purpose of a clothing. The technological sewing process is performed on production lines and contains a large number of work places where technological operations are carried out. In the technological process of sewing men's suits depending on the model complexity, the technological sewing process consists of 170 to 186 technological operations. The structure of the technological sewing operation consists of neces-

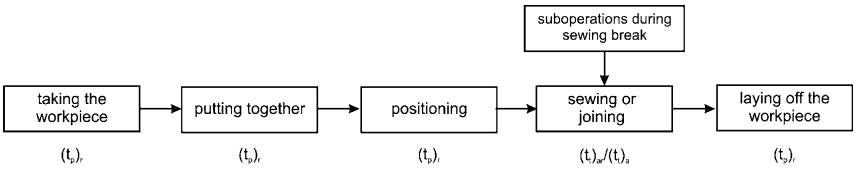


Fig.1 Classification of the technological sewing operation into suboperations [10]

Tab.1 Suboperations of the technological operation of sewing and methods of its perform [10]

Suboperations	Method of performing the suboperation
taking	taking one work piece from one bundle taking two work pieces from one bundle taking two work pieces from two bundles taking three work pieces from three bundles
putting together	putting together of the contour edges putting on the marked place
positioning	positioning under the presser foot positioning of the work piece under the needle guided by the foot motion positioning of the work piece in front of the needle
sewing	joint guidance basic guidance individual guidance guidance with puckering guidance of work piece using a ruller seam bartacking by the lever of the bartacking mechanism seam bartacking by the bartacking button programmed (automatic) seam bartacking thread trimming using the scissors thread trimming using the trimming device thread trimming using the automatic thread trimming mechanism
suboperation during sewing break	alignment of the contour edges rotation around the needle
laying off	with one hand with both hands

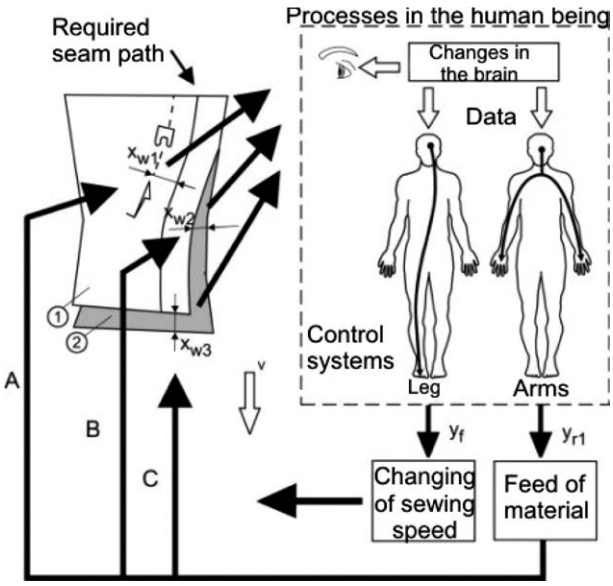


Fig.2 Control loops while guiding the work piece during sewing the seam where: A – control loop of the seam location; B – control loop of the position of the material edges; C - control loop of the position of the length of the work piece layers [2]

sary support-hand suboperations such as: taking, putting together, positioning, suboperations during sewing breaks and laying off as well as technological machine-manual suboperations of sewing (Fig.1) [10].

Individual suboperations in the structure of the technological operation can be carried out in several ways depending on the size and number of work pieces, degree of the technical equipment of sewing machines, size and form of the work surface, necessary work zones and visual fields as well as level of worker training (Tab.1) [10].

Suboperation of *taking* includes taking the work piece from the machine work surface, and it is performed with the set of basic motions: reaching (R) – grasping (G) – moving (M) whereby the work piece is transferred into the central work zone.

Suboperation of *putting together* includes putting together two or three cutting parts. This suboperation is performed in the central work zone. It requires high precision performing and control in the central visual field whereby motions P1SE and P2SE are used depending on the necessary degree of precision.

Suboperation of *positioning* consists of the simultaneous motion of moving (M), positioning under the needle (P1SE) and the foot motion for lifting and lowering the presser foot (FM).

Suboperations during *sewing breaks* can contain standard sets of work piece alignment and rotation under the needle. These suboperations depend on the method of performing the technological operation, the method of guiding and technical equipment of the sewing machine. They refer to sewing on universal and special sewing machines.

Suboperation of *laying off* the work piece includes laying off work pieces with one hand (for small-sized work pieces) or with both hands (for larger work pieces) onto the auxiliary stand, and they are performed with motions of moving (M), releasing off (RL) and returning to the equilibrium position (R).

With regard to the sewing machine type used, suboperation of *sewing* can be machine suboperation, e.g. when sewing on the automatic sewing machine or machine-manual suboperation, e.g. when sewing on the universal or special sewing machine where the guidance of the work piece during sewing is part of the technical suboperation [11].

While performing technological sewing suboperations on universal and special sewing machines, the machine-manual technological sewing suboperation involves the interaction between the machine and the worker, i.e. the worker guides the work piece during sewing the seam.

While performing the machine-manual sewing suboperation during guiding the work piece, three degrees of freedom of movement are present, i.e. three independent control loops with feedback regarding the seam location in relation to the material edges (A), mutual position of the material edges (B) and the position of the length of the work piece layers (C) (Fig. 2). The simultaneous information of the individual control loops (A, B, C) is superimposed depending on the required precision (1-2 mm) of guiding the work piece, so the foot motion controls the sewing machine according to the psychophysical reaction ability of the worker.

In order to achieve the efficiency, the quality and the continuous sequence of the technological sewing process, it is necessary to develop optimal work methods [12]. The shape (straight or curved, curvature radius) and the length of the seam contour as well as fabric type and fabric design, required quality and seam location play an important role in the selection of a working method particular technological sewing operation [13, 14]. Furthermore, the selection of a suiTab.work method is related to the design of the workplace (bundle arrangement, size and height of the work surface, height of the seat, the compliance of the workplace with the anthropometric measurements of workers, the assure of pleasant microclimatic conditions, lighting), the type and degree of technical equipment of the sewing machine, the system of workplace installation [15].

When determining the work method, it is necessary to take into account the type of the technological operation,

the quality requirements of the production, and the principles of the cost-effectiveness of the sequence of motions. Taking into account the ergonomic, technical and technological factors of workplace design and the selection of a suitable work method appropriate workplace stability, shorter time of performing the technological operation, lower workload and manufacturing quality are enabled.

When determining a suitable work method, it is necessary to investigate the possibility of simultaneous and combined motions, which reduces the time of hand and machine-manual suboperations, the introduction of work equipment and auxiliary devices that reduce worker workload.

When determining the method of work piece guiding or the work method in the sewing process, it is necessary to achieve the cost-effectiveness of movements and a suitable position of work piece layers. The following principles should be taken into account in order to perform the technological sewing operation in an optimal manner [16, 17]:

- work piece should be guided approx. 15 cm away from the presser foot so that it is possible to correct the line in case of a deviation from the required seam location,
- the left hand should hold the work piece at such a distance that it is not necessary to release off and grasp again during sewing,
- laying off the work piece is performed with motions for moving and releasing off within the normal work zone,
- the location of the work pieces on the work surface should enable an ergonomically suitable sequence of motions: reaching – grasping – moving within the normal work zone. Combined motions with both hands are used for medium sized and larger work pieces.
- the worker should take the work piece with the same hand used for guiding in the sewing process,
- when taking work pieces and putting them together, a higher degree of motion coordination is necessary,
- specified technical equipment of the sewing machine such as automatic cutting off the thread and programmed seam bartacking is necessary,
- average length of the seam sewn in one segment without stopping should range from 30 to 35 cm,
- when taking 2 work pieces from the work surface the worker takes with the right hand the lower work piece layer on the upper edge from 2 to 5 cm away from the foreseen seam beginning, while at the same time he/she takes with the left hand the upper work piece at a distance from 2 to 5 cm away from the foreseen seam beginning. That enables putting together the work piece without additional aligning.

The MTM system can be used for creating work methods, determining time norms and designing work places already in the phase of designing production processes of work systems and workplaces as well as redesigning the existing workplace. In creating work methods the technological operation is take apart into suboperations and basic motions. Based on an analysis the most favourable work method is determined and elaborated with the time of performing the technological operation.

The determination of the optimal work method with the belonging normal time consists of:

- collecting information on the technological operation whereby the most suitable sewing machine is determined,
- designing of workplace and adapting to the anthropometric measurements of workers whereby work and visual zones are determined,
- take apart the technological operation into suboperations and motions and
- determining basic motions using the MTM system with the possibility of performing combined and simultaneous motions.

Based on this procedures, the optimal work method is determined with the normal belonging time for performing motions, suboperations and technological operation.

By developing a favourable work method is achieved the use of lower-level motions which resulting in shorter perform time, uniform work rhythm, higher degree of motion coordination, lower degree of necessary visual control which at the same time affects the reduction of workload.

3. Experimental part

In the framework of the scientific projects implemented at the University of Zagreb Faculty of Textile Technology in the Department of Clothing Technology, systematic recordings of characteristic workplaces in the production lines in the clothing industry (Kotka, Krapina, Virovitičanka, Virovitica; Pounje, Hrvatska Kostajnica; Mara, Osijek; EMKA, Pregrada) using appropriate video equipment was carried out. By analysing video recordings, basic data on the existing methods of performing technological operations at individual workplaces were obtained. Using the MTM system a systematic development and determination of standard sets of individual motions were carried out which are based on the logical sequence of basic motions.

To record technological sewing suboperations, a SONY DCR-HC42E video camera with time generator was used. It allows time measurement with a precision of ±0.1 s and it has the possibility of data entry. The video camera was positioned so that the workplace was in the visual field in a side-view allowing a recording with maximum zones of dynamic motions while carrying out the work process.

In the structure of the technological operation, the sewing suboperation is the basic purpose of work at the workplace, and it is performed with a

Tab.2 Suboperations performed during sewing and ways of their performing

Suboperations	Method of performing the suboperation
Work piece guiding	Joint guiding (D01) Basic way of guiding (D02) Individual guiding (D03) Guiding with puckering (D04)
Seam bar tacking	With the lever of the seam bar tacking mechanism (U01) With the button for seam bar tacking (U02) Programmed (automatic) seam bar tacking (U03)
Use of auxiliary devices	Positioning and guiding of the work piece by using the ruller (E04)
Thread trimming	With normal scissors (F01) With special scissors (F02) With the thread trimming mechanism (F03) With the thread trimming device (F04)
Suboperation during sewing break	Change of the grip (G01) Alignment of the contour edges by changing the grip of the right hand (G02) Alignment of the contour edges by changing the grip of both hands (G03) Rotation of the work piece around the needle with one hand (G04) Rotation of the work piece with both hands (G05)

certain sewing accuracy, achieved by coordinated hand and foot motions when performing simultaneous and combined motions, and by the concentration of the eye view.

Using the MTM system individual standard sets contained in the technological sewing suboperation were taken apart into basic motions according to necessary performance variables: motion length, precision and dynamics, necessary visual control, and possibilities of performing combined and simultaneous motions. Within the technological sewing suboperation method of work piece guiding (D), method of seam bartacking (U), positioning and work piece guiding using auxiliary devices (E), method of cutting off the thread (F) and suboperations during sewing breaks (G) (Tab.2) were developed.

4. Results

The selection of the method of work piece guiding during sewing depends on fabric properties, contours of the cutting parts, nominal sewing speed, specific stitch density and the level of worker training, whereby it differs according to: method of joint guiding (D01), basic method of guiding (D02), method of individual guiding (D03) and work piece guiding with puckering (D04).

Method of joint guiding (D01) is performed so that the left hand is placed with the whole palm surface across the upper part of the work piece (contact by touching G5) while the right hand grasps the upper and lower layer of the work piece (thumb - fore finger - middle finger system) whereby the worker guides, controls and corrects the seam distance from the contour edges (Fig. 3).

When using the method of joint guiding with simultaneous controlling and holding the work piece with both hands the two layers work piece is guided together during sewing. The position of the left hand is at the approximate length of the bar tack of the individual segment (approx. 20 to 30 cm), while the right hand guides, controls and corrects the edges of the

Fig.3 Representation of the sequence of motions using the method of joint guiding on the universal sewing machine

Fig.4 Representation of the sequence of motions with one control point

Fig.5 Representation of the sequence of motions for the basic guiding method with two control points

Fig.6 Representation of the sequence of motions for the method of individual work piece guiding

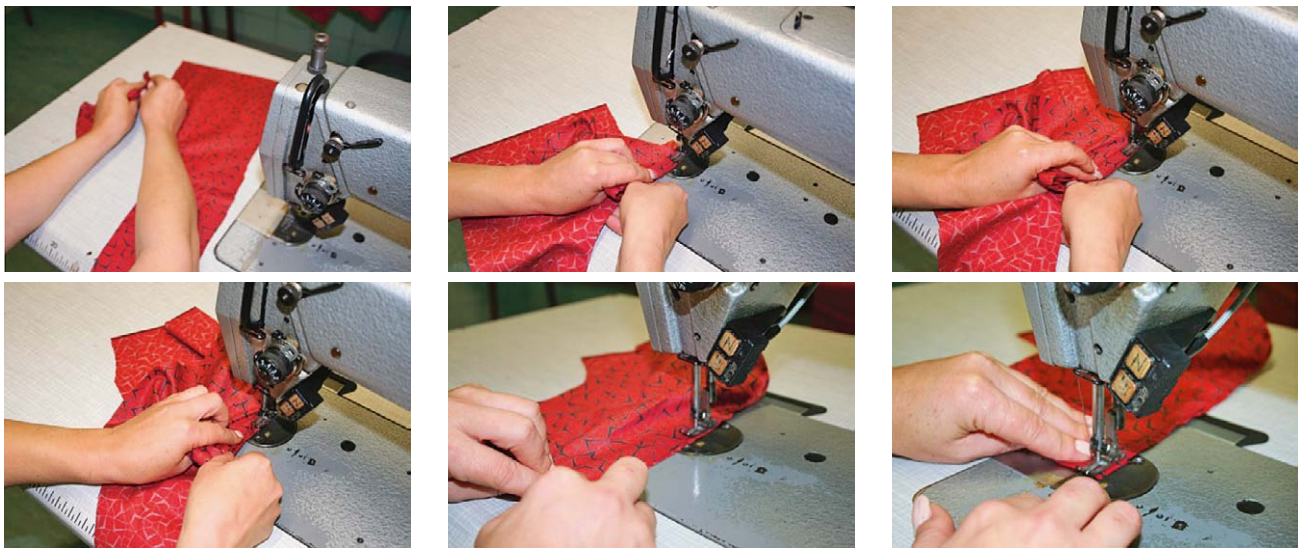


Fig.7 Representation of the sequence of motions for the method of guiding with puckering

seam contours. This method is used to overlock one material layer or to join two layers of the small-sized or medium-sized work piece, which have straight or slightly curved contours.

Basic method of work piece guiding (D02) is the method where the cutting parts were previously put parallel and prepared for the sewing process. Considering of the length and curvature of the contours of the cutting parts, the basic method of work piece guiding can be with one or two control points. The basic method of work piece guiding with one control point (D02/1) is performed so that after positioning the work piece with the left hand the work piece is grasped with the G1A motion along the length, and the work piece is guided and controlled with the same hand during the sewing process. This method is used with work pieces with straight and slightly curved contours up to 35 cm long (Fig. 4).

The basic method of guiding with two control points (D02/2) is performed so that after positioning the work piece is grasped with the left hand with G1A motion along the length (first control point), and with the right hand with G1A motion along the half-length (second control point). The work piece is pushed to the side with the left hand so that it is possible to monitor the seam location during sewing. The sewing process is carried out without break to the end of the second control point whereby the work piece is guided with the right hand. Afterwards, the work piece is put parallel with the work surface using the left hand and is guided to the seam end. At longer work pieces the joining marks on the edges make the technological suboperation easier. This method is used

Tab.3 Standard set of motions for seam bar tacking using the lever of the bar tacking mechanism (U01)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1			9.5	R30A	Reach for the lever
2			0.0	G5	Grasp the lever
3	Activate the pedal	FM	8.5	(M4A/AF)	Press the lever
4			0.0	RL2	Release the lever
5			12.8	R30B	Return the hand to the work piece
		∑TMU (s)	30.8 (1.11)		

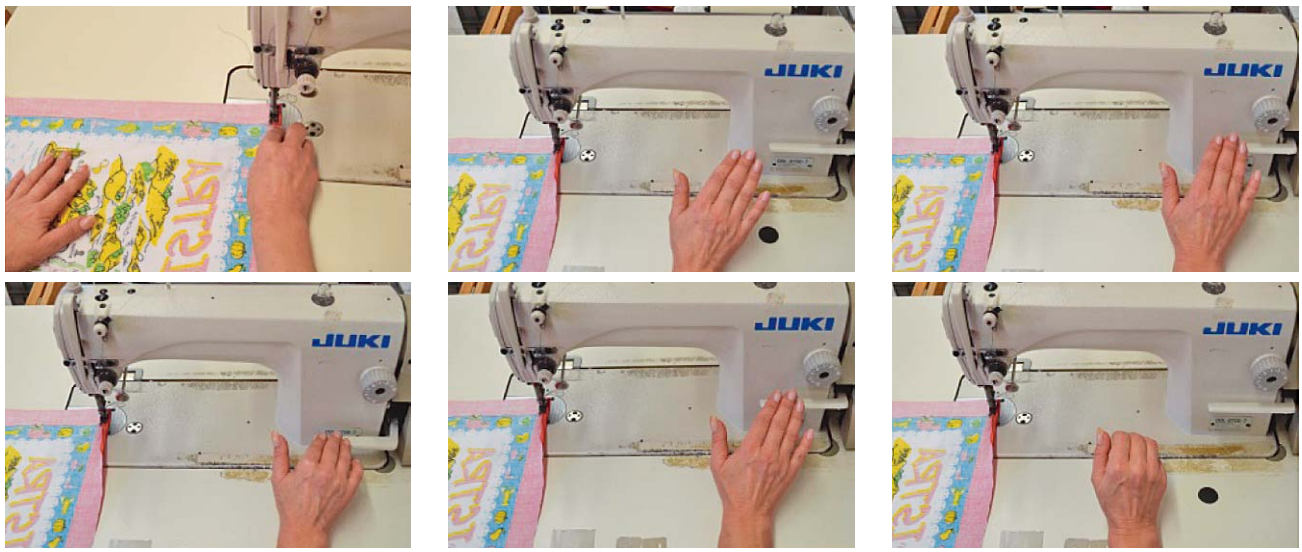


Fig.8 Representation of the sequence of motions for seam bar tacking using the lever of the bar tacking mechanism

Tab.4 Standard set of motions for seam bar tacking using the bar tacking button (U02)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1			6.1	R10A	Reach for the button
2			0.0	G5	Grasp the button
3	Activate the pedal	FM	8.5	(AF)	Press down the button
4			0.0	RL2	Release the button
5			6.3	R10B	Return the hand to the work piece
		∑TMU (s)	20.9 (0.75)		

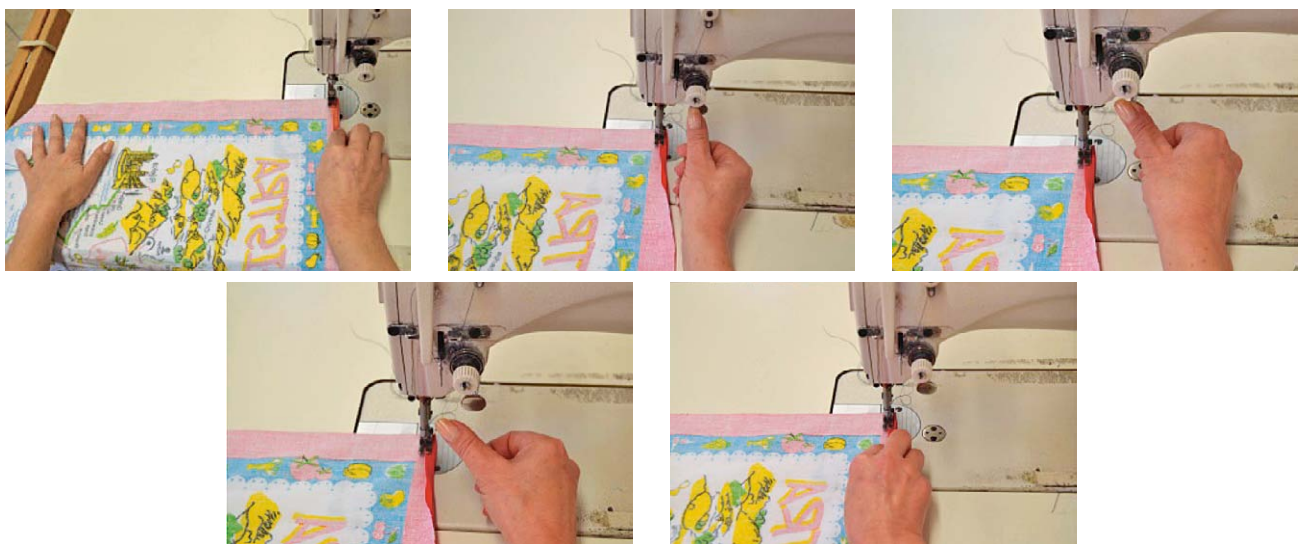


Fig.9 Representation of the sequence of motions for seam bar tacking using the bar tacking button

Tab.5 Standard set of motions for work piece positioning using the auxiliary device – ruler (E04)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1	Transfer the work piece to the stop	(M6A)	0.5	FM	Lift the presser foot
2			8.5	FM	Lower the presser foot
			0.0	RL2	Release off
		∑TMU (s)	17.0 (0.61)		

Fig.10 Representation of the sequence of positioning the work piece using the auxiliary device – ruler

with straight and slightly curved contours up to 100 cm long (Fig.5).

Method of individual work piece guiding (D03) is performed so that after positioning the work piece the left hand grasps the upper work piece with G1A motion and the right hand grasps the lower work piece with G1A motion, and allow them to slide slowly through the fingers during the sewing process whereby the seam distance from the contour edge is simultaneously guided, controlled and corrected (Fig.6). With this method, the work piece layers are guided separately and joined immediately before the presser foot. This type of work guiding is used to sew two layers of the work piece with straight, slightly curved contours or with contours with different radii of curvature.

Method of work piece guiding with puckering (D04) is performed so that when taking the work piece with the left hand with puckering the upper part of the work piece is grasped and held with G1A motion, while the right hand is in the position of grasping with G1A motion using the thumb and the fore finger. During sewing the upper and lower part of the work piece is let out allowing continuous sewing and controlling the sewing precision (Fig. 7). The separate work piece guidance is characteristic of this guiding method during sewing curved contours with different radii of curvature.

Depending on the type of the technological operation, the type and properties of the seam (length and seam location) the following sewing methods are differentiated:

a) short seam (one sewing segment)
   - seam beginning with bar tacking
   - seam with end bar tacking
   - seam with beginning and end bar tacking
   - seam without beginning and end bar tacking

b) long seam (two or several sewing segments
   - seam beginning with bar tacking
   - seam with end bar tacking
   - seam with beginning and end bar tacking
   - seam without beginning and end bar tacking
   - seam with changing the sewing direction.

Seam with beginning and/or end bar tacking is performed mostly with from 3 to 5 stitches with changing the sewing direction, and depending on the technical equipment of the sewing machine the method of bar tacking a differentiation is made between: lever of the bar tacking mechanism (U01), bar tacking button (U02) and programming the number of stitches for seam bar tacking on sewing machines with processing microcomputer (U03).

On machines equipped with the lever of the bar tacking mechanism (U01) a motion of the right hand reaches for the lever of the mechanism, and by pressing the mechanism is activated reverse sewing and by deactivating the lever and by reaching the hand returns to the work piece. This set of motions is performed simultaneously with the motion of moving the work piece to the needle (M6C), by reaching out the hand to the lever of the mechanism (M30A) and activating the sewing machine by moving the foot (front foot flexion FM). These motions are performed simultaneously and they are out of the central visual field and belong to class II; thus, a certain period for training is necessary (Tab.3, Fig. 8).

On machines equipped with *the bar tacking button* (U02) the right hand reaches for the button, the button for reverse sewing is pressed down with the thumb to activate it, and the hand returns to the work piece (Tab.4, Fig. 9). These motions are performed in the central visual field and belong to class I, and period for training is not necessary.

On the contemporary sewing machines *equipped with the processing microcomputer* (U03) the seam bar tacking is programmed by the microcomputer as a number of stitches in seam beginning bar tacking and/or

Tab.6 Standard set of motions for cutting off the thread using the normal scissors (F01)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1			8.5	FM	Lift the presser foot
2	Pull the work piece out under the needle	M10B	6.8		
3			11.4	R25B	Reach for the scissors
4			5.6	G5/G2	Grasp the scissors
5			10.5	M20B	Move the scissors into the work zone
6			5.8	M6C	Move the scissors to the thread
7			(2.0)	(M2A)	Open the scissors simultaneously
8			3.4	AF	Press the scissor blades
9			(2.0)	(M2A)	Cut off the thread simultaneously
10			11.2	M25A	Lay off the scissors
11			2.0	RL1	Release off the scissors
12			10.8	R25B	Return the hand to the work piece
		∑TMU (s)	76.0 (2.74)		

Fig.11 Representation of the sequence of motions for cutting off the thread using normal scissors

Tab.7 Standard set of motions for cutting of the thread with special scissors (F02)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1			8.5	FM	Lift the presser foot
2	Pull the work piece out under the needle	M4B	4.0		
3			5.8	M6C	Move the scissors to the thread
4			3.4	AF	Press the scissors blades
5			(2.0)	(M2A)	Cut off the thread simultaneously
		∑TMU (s)	21.7 (0.78)		

Tab.8 Standard set of motions for cutting off the thread with thread trimming mechanism (F03)

No.	Motion description	Symbol	TMU
1	Foot motion	FM	8.5
2	Response time for automatic lifting of the presser foot and the needle, and response time for activating the thread trimming mechanism	t_{aok}	4.0
3	Foot motion	1/2 FM	4.3
		∑TMU (s)	16.8 (0.61)

seam end bar tacking. Thus, on sewing machines with processing microcomputer seam bar tacking is performed automatically without additional hand movements.

During the technological sewing suboperation using auxiliary devices such as rulers, guiding of work piece are easier during the sewing process due to the reduced number of degrees of freedom. Positioning the work piece using a ruler includes moving the work piece to the ruler and lifting the presser foot, lowering the presser foot and releasing off the work piece (Tab.5, Fig.10).

The use of a ruler in performing the technological sewing operation allows continuous sewing of longer seam segments and sewing at higher stitch speeds with less visual and musculature control of the worker, resulting in reducing the time of performing the technological operation and worker workload.

The thread is cut off after the sewing suboperation in the technological

Tab.9 Standard set of motions for cutting off the thread with the thread trimming device (F04)

No.	Left hand movement description	Symbol	TMU
1	Move to the trimming device	M10C	7.9
2	Cut off	AF	3.4
		∑TMU (s)	11.3 (0.41)

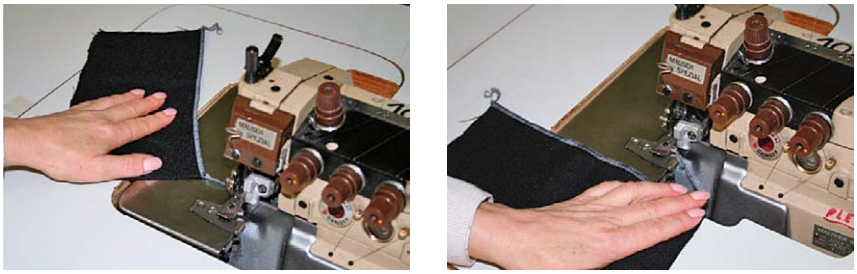


Fig.12 Representation of the sequence of motions for cutting off the thread with thread trimming device

sewing operations depending on the technical equipment of the sewing machine. The thread can be cut off manually using the scissors (normal (F10) or special (F02) scissors), on the machine using the thread trimming mechanism (F03) or using the thread trimming device (F04). These standard sets of motions interrupt the dynamic flow and rhythmicity of performing technological operations, requiring good level of worker training and coordination of movements of workers.

Cutting off the thread *using the normal scissors* (F01) includes lifting the presser foot and the machine needle by pressing down the pedal, pull-

Tab.10 Standard set of motions to change the grip (G01)

No.	Right hand movement description	Symbol	TMU
1	Release off the work piece	RL1	2.0
2	Reach the arm to another place	mR30B	9.9
3	Grasp the work piece	G1A	2.0
		∑TMU (s)	13.9 (0.50)

Fig.13 Representation of the sequence of motions to change the grip

Tab.11 Standard set of motions for aligning the contour edges with changing the grip of the right hand (G02)

No.	Right hand movement description	Symbol	TMU
1	Release off the work piece	RL1	2.0
2	Reach the hand to another place	mR30E	10.2
3	Grasp the work piece	G1A	2.0
4	Parallel putting and joining	M6C/P1SE	11.4
		∑TMU (s)	25.6 (0.92)

Fig.14 Representation of the set of motions for aligning the contour edges with changing the grip of the right hand

Tab.12 Standard set of motions for aligning the contour edges with changing the grip of both hands (G03)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1	Release off the work piece	RL1	2.0	(RL1)	Release off the work piece
2	Reach the arm along the edge	mR30E	11.4	(R25E)	Reach the arm along the edge
3	Grasp the work piece	G5/G2	5.6	(G1B)	Grasp the work piece
4	Align the edge	M6C	5.8	(M2C)	Align the edge
5	Putting together	P1SE	5.6	(P1SE)	Putting together
6	Contact grasp	G5	0.0	(G5)	Contact grasp
		∑TMU (s)	30.4 (1.09)		

Fig.15 Representation of the set of motions for aligning the contour edges with changing the grip of both hands

Tab.13 Standard set of motions to rotate the work piece around the needle with one hand (G04)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1			8.5	FM	Lift the presser foot
2	Rotate the work piece	M25C	13.4		
3	Kinematic reaction	t_{rr}	4.0		
4	Lower the presser foot	FM	8.5		
		∑TMU (s)	34.4 (1.24)		

Fig.16 Representation of the sequence of motions for rotating the work piece around the needle with one hand

ing the work piece out under the needle, reaching for and grasping the scissors, taking the scissors to the thread and its cutting off (Tab.6, Fig.11).

This suboperation requires practical experience of the worker who lays off the scissors always on the same place and in the same position suiTab.for next taking. It is used on sewing machines which do not have the option of cutting off the thread with thread trimming mechanism.

Cutting off the thread *with special scissors* (F02) includes lifting the presser foot and the needle of the sewing machine, pulling the work piece out under the needle, moving the work piece with the right hand with scissors to the thread and cutting off the thread. The special scissors for cutting off the thread are held in the right hand during the entire sewing process so that the process of cutting off the thread is shorter (Tab.7). This type of cutting off the thread is used on sewing machines which do not have the option of cutting off the thread with thread trimming mechanism

Cutting off the thread with *thread trimming mechanism* (F03) is performed on the contemporary machines equipped with automatic thread trimming mechanism. In case of this suboperation the motion of the foot and the pressure of the heel backwards on the pedal lift the presser foot into the upper position, then the thread trimming mechanism is activated (Tab.8).

Cutting off the thread *with thread trimming device* (F04) is performed at the end of the sewing process on special sewing overlocking machines. The left hand guides the work piece to the thread trimming device to trim the material edges and the

Tab.14 Standard sets of motions for the rotation of the work piece around the needle with both hands (G05)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1			8.5	FM	Lift the presser foot
2	Rotate the work piece	M30C	15.1	(M15C)	Rotate the work piece
3	Kinematic reaction	t_{rr}	4.00		
4	Lower the presser foot	FM	8.5		
		∑TMU (s)	36.1 (1.30)		

Fig.17 Representation of the sequence of motions for the rotation of the work piece around the needle with both hands

thread. It is located on the right side in front of the needle and the thread is cut off (Tab.9, Fig. 12).

A seam from 30 to 35 cm long can be sewn in one segment depending on seam properties, nominal stitch speed of the sewing machine, sewing speed, specific stitch density and level of worker training. During sewing break individual suboperations are performed which enable easier handling of the work piece and facilitate the sewing process. They can be devided into the following suboperations: grip change (G01), aligning contour edges with changing the grip of the right hand (G02), aligning the contour edges with changing the grip of both hands (G03), rotation of the work piece around the needle with one hand (G04), rotation of the work piece with both hands (G05). Suboperations during sewing breaks are performed on the work surface of the machine in the central visual field.

Change of the grip (G01) is performed so that the right hand release off the work piece in a certain position and then it reach along the edge to a new position where it grasps the work piece with G1A motion (Tab.10, Fig.13).

Aligning the contour edges with changing the grip of the right hand (G02) is performed by moving the grip of the right hand along the edge of the work piece with simultaneous precise aligning (Tab.11, Fig.14).

The suboperation of aligning the contour edges with changing the grip of the right hand is used during sewing break when joining two or three large or very large work piece layers.

Aligning the contour edges with changing the grip of both hands (G03) includes changing the grip of both hands at a length of 30 cm, whereby the left hand grasps the upper layer, and the right hand grasps the lower layer of the work piece. Afterwards both work piece layers are put together (Tab.12, Fig.15).

This suboperation is performed to prepare the work piece for positioning under the sewing needle. The suboperation of aligning the work piece edges with changing the grip of both hands is used during the sewing process and it depends on the level of worker training and the work method used for performing the technological operation.

Rotation of the work piece around the needle with one hand (G04) is performed with smaller work pieces so that during sewing break due to changing the sewing direction the presser foot is lifted with a motion of the foot whereby the needle stays in its lower position, and the left hand rotates the work piece to the foreseen position (Tab.13, Fig.16).

Rotation of the work piece around the needle with both hands (G05) is performed with larger work pieces so that in the position of changing the sewing direction with a motion of the foot the presser foot is lifted whereby the needle stays in the lower position, and the work piece is rotated with both hands to the foreseen position (Tab.14, Fig.17).

Time amounts of the machine-hand technological suboperation of sewing depend on working properties and equipment of the sewing machine, seam properties (seam length, straight or curved seams) and fabric type to be sewn (patterned fabric). The method developed by Heckner [18] is used for the calculation of normal machine-hand times of the technological sewing suboperation. Systematic research activities for determining normal machine-hand times of the technological suboperation of sewing different seam shapes and lengths were undertaken by S. Firšt Rogale et al. who developed and established new modern methods for calculating normal machine-hand times for sewing straight (RAV method) and curved (ZAK and MONOR method) contours of cutting parts and seams, respectively [19-21].

5. Discussion

Technological sewing operations are carried out on sewing machines char-

acterized by machine-hand work, whereby the worker and the machine work together while simultaneously performing the sewing process. Considering the physical-mechanical properties of the work piece, handling should be careful which requires extremely good motoric skills that are manifested in the mobility of chest, hand and leg and their coordinated action, good tactile ability as well as ability of oculomotor coordination. Considering psychomotoric abilities and the level of worker training, the worker adjusts the sewing speed with a motion of the foot consistent with his/her sensor and motoric abilities in the technological sewing suboperation.

Technological sewing suboperation consists of work piece guidance method, seam bar tacking, guiding the work piece using a ruler, cutting off the thread, and suboperation during sewing break.

Fabric properties, shape and curvature of the contours of cutting parts, nominal stitch speed, seam length, technical equipment of the sewing machine and level of worker training affect the method of work piece guiding. In view of the above-mentioned the following methods are differentiated: method of joint guiding (D01), basic method of work piece guiding (D02), method of individual work piece guiding (D03) and method of work piece guiding with puckering (D04). The method *of joint guiding the work piece* (D01) is used in sewing one or two layers of straight or slightly curved contours. *The basic method of work piece guiding* (D02) is used in sewing small and medium sized work pieces with straight or slightly curved contours. It is differentiated between guiding the work piece with one (D02/1) and with two control points (D02/2) depending on the length of the cutting part. *The method of individual guiding* (D03) is used for sewing two work piece layers with straight and slightly curved contours or contours with different radii of curvature. *The method of guiding with puckering* (D04) is used for sewing work pieces with different contour shapes or for sewing patterned fabrics.

Depending on the technical equipment, the sewing machines have possibilities bar tack the seam using the lever of the seam bar tacking mechanism (U01), seam bar tacking button (U02), and programmed bar tacking using the processing microcomputer (U03).

When the lever of the bar tacking mechanism (U01) (Tab.3, Fig. 8) is used for bar tacking, a set of motions of the right hand is performed whereby the worker reaches for the lever with R30A/G5 motions, presses down the lever with M4A/AF motions which activates the mechanism for reverse sewing. Afterwards, performing RL2/R30B motions, the worker releases the lever and returns the hand to the work piece. The sewing direction changes within the basic motion M4A/AF and is performed by a foot motion (FM) to control the sewing process, requiring a good hand and leg coordination as well as a high level of worker training. The length of reverse sewing, i.e. seam bar tacking depends on the duration of pressure on the lever with AF motion. The time of performing the set of motions takes 30.8 TMU (1.11 s). This set of motions is performed at seam beginning bar tacking and/or seam end bar tacking.

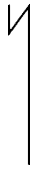
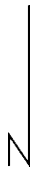
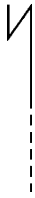
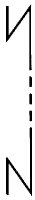
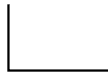
Depending on the technical equipment, the universal sewing machine may have a *seam bar tacking button* (U02) (Tab.4, Fig. 9). With a set of R10A/G5 motions the right hand reaches for the button, by pressing AF the mechanism for reverse sewing is activated, and with a set of RL2/R10B motions the contact between the finger and the button is interrupted, and the hand returns to the work piece. The sewing direction changes during basic AF motion, and the duration of reverse sewing or seam bar tacking depends on how long the button is pressed (AF). The same set of motions of the right hand is used at seam beginning and/or seam end bar tacking. The time of the set of motions takes 20.9 TMU (0.75 s).

On the contemporary sewing machines with processing microcomputer, seam beginning bar tacking and/or seam end bar tacking is defined and programmed before sewing as stitch number (from 0 to 9 stitches) depending on seam requirements. This eliminates R30A/G5/M4A/AF/RL2/R30B motions which are necessary to perform seam bar tacking using the lever of seam bar tacking, i.e. R10A/G5/AF/RL2/R10B necessary to perform seam bar tacking using the bar tacking button.

In the technological sewing operation, auxiliary devices are upgraded on universal and special sewing machines whose purpose is to facilitate and accelerate the manufacture of certain seams, to improve seam quality and appearance. Rulers are installed on the base plate of the sewing machine and are used to guide one, two or more work piece layers at a specified distance from the needle. Using the rulers the necessary number of degrees of freedom decreases during the work piece guidance because the location or distance of the seam from the material edge is defined so that the worker during handling the work piece in the course of sewing has only one degree of freedom (sewing direction). *Positioning of the work piece by using a ruler* (E04) includes the set of FM (M6A)/FM/RL2 motions whose time takes 17.0 TMU (0.61 s). By using a ruler, worker fatigue and workload decrease, the number of sewing breaks also decreases which affects seam quality and appearance and contributes to increasing the sewing speed because work piece handling has only one degree of freedom.

Cutting off the thread is performed after the technological sewing operation. Depending on the technical equipment of the sewing machine the following tools can be used: normal scissors (F01) or special scissors (F02), automatic thread trimming

Tab.15 Possibilities of performing the technological sewing suboperation considering seam length and method of seam bar tacking

No.	Seam	Seam length	Sewing suboperation	Designation
1.		Short seam – without bar tacking (one segment)	Activate the pedal Sewing Cut off the thread	FM t_{ar}/ D01; D02; D03 F01; F02; F03; F04
2.		Short seam – seam beginning bar tacking (one segment)	Activate the pedal Seam beginning bar tacking Sewing	FM U01, U02, U03 t_{ar}/ D01; D02; D03 F01; F02; F03
3.		Short seam – seam end bar tacking (one segment)	Activate the pedal Sewing Seam end bar tacking Cut off the thread	FM t_{ar}/ D01; D02; D03 U01, U02, U03 F01; F02; F03
4.		Short seam – seam beginning and seam end bar tacking (one segment)	Activate the pedal Seam beginning bar tacking Sewing Seam end bar tacking Cut off the thread	FM U01, U02, U03 t_{ar}/ D01; D02; D03 U01, U02, U03 F01; F02; F03
5.		Long seam – seam beginning bar tacking (two or several joining segments	Activate the pedal Seam beginning bar tacking Sew one segment (approx. 10-15 cm) Align Sewing 2 segments (approx. 30-35 cm) Cut off the thread	FM U01, U02, U03 t_{ar}/ D01; D02; D03 G02;G03 t_{ar}/ D01; D02; D03 F01; F02; F03
6.		Long seam – seam end bar tacking (two or several joining segments)	Activate the pedal Sewing 1 segment (approx. 10-15 cm) Align Sewing 2 segments (approx. 30-35 cm) Seam end bar tacking Cut off the thread	FM t_{ar}/ D01; D02; D03 G02;G03 t_{ar}/ D01; D02; D03 U01, U02, U03 F01; F02; F03
7.		Long seam (without bar tacking (two or several joining segments)	Activate the pedal Sewing 1 segment (approx. 10-15 cm) Align Sewing 2 segments (approx. 30-35 cm) Cut off the thread	FM t_{ar}/ D01; D02; D03 G02;G03 t_{ar}/ D01; D02; D03 F01; F02; F03
8.		Long seam – seam beginning and end bar tacking (two or several joining segments)	Activate the pedal Seam beginning bar tacking Sewing 1 segment (approx. 10-15 cm) Align Sewing 2 segments (approx. 30-35 cm) Seam end bar tacking Cut off the thread	FM U01, U02, U03 t_{ar}/ D01; D02; D03 G02;G03 t_{ar}/ D01; D02; D03 U01, U02, U03 F01; F02; F03
9.		Long seam – sew with changing the sewing direction (two or several joining segments)	Activate the pedal Sewing 1 segment (approx. 10-15 cm) Rotate Align Sewing 2 segments (approx. 30-35 cm) Cut off the thread	FM t_{ar}/ D01; D02; D03 G04, G05 G02, G03 t_{ar}/ D01; D02; D03 F01; F02; F03

mechanism (F03) or thread trimming device (F04).

Normal scissors (F01) are used for thread trimming on sewing machines without the automatic thread trimming mechanism or thread trimming device. After the sewing process the worker pulls the work piece out under the presser foot (M10B) with her left hand and takes the scissors (R25B/G5/G2) with her right hand, transfers the scissors to the thread with opening the scissors (M20B/M6C/(M2A), cuts off the thread (AF/(M2A), lays off the scissors and returns the hand to the work piece (M25A/RL1/R25B), (Tab.6, Fig.11). Normal time of performing the set of motions takes 76.0 TMU (2.74 s).

Special scissors (F02) are used for thread trimming on sewing machines without the automatic thread trimming mechanism or thread trimming device. The special scissors are ergonomically designed and are held in the right hand. Their use reduces dynamicity and precision of motion performing. The suboperation of thread trimming with the special scissors is performed so that after sewing the worker pulls the work piece out under the presser foot (M4B) with her left hand, she transfers the scissors with her right hand to the thread, and by pressing the scissors blades she simultaneously cuts off the thread (M6C/AF/(M2A)) (Tab.7). Normal time of performing the suboperation takes 21.7 TMU (0.78 s).

Automatic thread trimming using *the thread trimming mechanism* (F03) is performed by moving the foot or by pressing the heel on the pedal whereby the presser foot and the needle are automatically lifted and the thread trimming mechanism is activated (Tab.8). Normal time of performing the suboperation takes 16.8 TMU (0.61 s).

Thread trimming using *the thread trimming device* (F04) is used on the special overlock sewing machine whereby at the end of sewing the left hand transfers the work piece to the thread trimming device (Tab.9, Fig.12). Normal time of performing the suboperation takes 11.3 TMU (0.41 s).

Suboperations during sewing breaks can help during machine-hand suboperations of sewing larger cutting parts (seam lengths >35 cm) since seam lengths from 30 to 35 cm can be sewn in one seam segment. During sewing break the grip is changed (G01), contour edges are aligned with changing the grip of one or both hands (G02, G03) and rotation around the needle is performed with one or with both hands (G04, G05). These standard sets of motions are performed in the central visual field of the worker. The location of the work piece with the support under the presser foot causes a reduced degree of freedom of motions, but it allows joining and rotating the work piece. The contour edges are aligned during breaks of sewing seam lengths longer than 35 cm or greater radii of curvature. While aligning the work piece during sewing break the worker changes the position from the forward to the central sitting position, which requires a certain level of training, and perform of simultaneous and combined motions. Work piece rotation around the needle is the procedure in which a change of sewing direction occurs whereby the needle should stay in the lower position. On the contemporary sewing machines with processing microcomputer the needle is in the lower position when a sewing break occurs, and with a foot motion (FM) only one presser foot is lifted so that the worker can rotate the work piece in order to sew the next seam segment.

*Grip change (*G01) is performed in order to control the work piece and to align contour edges with (RL1/mR30B/G1A) motions (Tab.10, Fig.13). Normal time of performing the suboperation takes 13.9 TMU (0.50 s).

Aligning the contour edges with grip change of the right hand (F02) is performed with the set of (RL1/mR30E/G1A/M6C/P1SE) motions (Tab.11, Fig. 14). It is used as a preparation for performing the technological sewing suboperation. Normal time of performing the suboperation takes 25.6 TMU (0.92 s).

Aligning the contour edges with grip change of both hands (G03) includes releasing off (RL1), reaching the arm along the work piece edge (mR30E), grasping (G5/G2) and joining (M6C/P1SE/G5) (Tab.12, Fig.15). Normal time of performing the suboperation takes 30.4 TMU (1.09 s).

Rotation of the work piece around the needle with one hand (G04) is performed with smaller work pieces in case of sewing break while the needle stays in the lower position (Tab.13, Fig. 16). Normal time of performing the suboperation takes 34.4 TMU (1.24 s).

Rotation of the work piece around the needle with both hands (G05) is performed in case of changing the sewing direction of larger work pieces. During sewing break the needle is in the lower position, and the worker uses the set of (FM/M30C(M15C)/FM) motions to perform the suboperation with both hands (Tab.14, Fig. 17). Normal time of performing the suboperation takes 36.1 TMU (1.30 s).

The developed standard sets of motions for the machine-hand suboperation of sewing allow determining the optimum working method depending on the type of the technological operation, seam length and seam characteristics. By selecting the work method and depending on the type of the technological operation, length, type and location of the seam sewing methods were analysed considering the number of seam segments. Tab.15 shows sewing suboperations for different seam lengths (short and long seam), different ways of seam bar tacking (without seam bar tacking, seam beginning bar tacking and/or seam end bar tacking) and sewing with change of direction.

The technological sewing suboperation is complex to perform due to required high accuracy and good workers' psychomotor abilities.

When performing technological sewing operations depending on the type of technological operation, length and characteristics of the seam, the method of performing the sewing suboperation is differentiated. The method of work piece guiding in the sewing process depends on the characteristics of the work piece contours (straight, curved, size of the radius of curvature). Seam bar tacking is performed depending on the type of the technological operation and its location on the garment. The method of seam bar tacking depends on the technical equipment of the sewing machine whereby several methods are used: seam bar tacking using the lever of the bar tacking mechanism, bar tacking button or by programming. Seam sewing can be performed without bar tacking, with seam beginning and/or seam end bar tacking. To bar tacking the seam, the level of worker training should be high, and the motion coordination of the worker should be appropriate because bar tacking is performed simultaneously with a foot motion. The seam length of cutting parts affects the number of sewing segments whereby in one segment the worker can bar tack from 30 to 35 cm of the seam without breaks which ensures satisfactory quality and precise perform of the technological operation. With short seams up to 20 cm long, the worker performs the technological operation in only one segment, i.e. without sewing break. With longer seams, the worker aligns the work piece during sewing break in order to achieve the required accuracy and quality of the seam. When sewing longer work pieces which require seam beginning bar tacking, the worker can bar tack the work piece to a maximum 10 to 20 cm followed by sewing break and aligning the work piece which complies with its sensory and motoric abilities because seam bar tacking interrupts the dynamism of the sequence of motions and the rhythmicity of perform. When sewing work pieces with a change in the direction of sewing after the suboperation of the work piece rotation, aligning follows to achieve the required quality of the second seam segment. Cutting off the thread with the scissors is carried out at the end of the sewing suboperation, which requires an appropriate level of worker training because the dynamic flow and rhythmicity of performing the technological operation is interrupted. When the programmed method of cutting off the thread is used, the heel pressure to the pedal lifts the needle and the presser foot, and further activating the pedal activates the thread trimming mechanism.

The developed sets of motions for sewing suboperations are used to determine optimal work methods depending on the requirements of the technological sewing operation, the length of cutting parts contours to be joined, the technical equipment of the sewing machine and the requirements on seam bar tacking.

6. Conclusion

Technological sewing suboperation is the basic purpose of work at the designed work place where functional change of work piece are done whereby the worker and the machine work together. The sewing suboperation is carried out with the visual focus in the central visual field whereby the worker works in the forward position and uses the hands to guide the work piece and the feet to adjust the stitch rate of sewing.

To determine support-hand suboperations contained in the technological sewing suboperation, the system of synthetic times MTM is used which makes it possible to develop standard sets of motions with belonging normal time of perform. Within the technological sewing suboperation there are 4 different methods of work piece guiding (D01-D04), 3 methods of seam bar tacking (U01-U03), guiding the piece work using the ruler (E04), 4 methods of cutting off the thread (F01-F04) and 4 methods of performing the suboperation during sewing break (G01-G04). The above mentioned methods of performing suboperations have been systematically and thoroughly described in the paper. Calculations of normal times of the duration of standard sets of motions are presented.

By combining standard sets of motions for sewing suboperations it is possible to determine the most favourable sewing method or the most favourable work method. The selection of individual standard sets of motions for the technological sewing operation depends on fabric properties, length and shape of seam contours of cutting parts, technological equipment of sewing machines, the level of worker training and the motoric (visual and tactile) abilities of the worker. With regard to the seam length (short and long seam) and its characteristics (straight, curved), nine basic sewing methods are differentiated.

By determining standard sets of optimal motions using the MTM system the process of finding the optimal work method, determining and analysing the time of performing the technological operation are accelerated because the work method can be defined already in the process of work place design. Standard sets of motions ensure the application of ergonomic principles in carrying out technological operations and designing work methods and workplaces, which reduces workload and perform time, and increases productivity.

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