VISUALISATION OF ANTHROPOMETRIC MEASURES OF WORKERS IN COMPUTER 3D MODELING OF WORK PLACE

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A B S T R A C T

Scientific 3D visualization of work place by computer made 3D-machine model and computer ckarateristics of animation of a worker have been done in this work. By visualization of 3D characters in inverse kinematic and dynamic relation with operating part of a machine, biomechanic characteristics of worker's body have been determined. For determination of dimensions of a machine inspection of technical documentation of machine has been done, measurement of machine and recording by camera was done, while anthropometric measures of body height of a worker were determined by measurement. On the basis of measured body heights, by computer program developed by an author all relevant anthropometric heights of a worker were determined. By knowing anthropometric measures, vision fields and scope zones while forming work places exact postures of workers while performing technological procedures were determined. Minimal and maximal rotation angles and translation of upper and lower arm which are basis for the analysis of worker burdening were analyzed. By computer anthropometric analysis of movement, dimension of seized space of a body are obtained, as for example range of arms, position of legs, head, back etc. Influence of forming of work place on correct postures of workers during work have been reconsidered and thus its consumption of energy and fatigue are reduced to minimal amount.

Introduction

Contemporary methods of industrial engineering and automation of technological processes have large significance in technological systems. They changed way of work and in this process it was noticed that a worker has limited possibility of action and adaptation to such changes and that such changes should be followed by suitable work humanization.

Industrial and techno-technological development imposed necessity of finding new constructions of machines and equipment but also new methods of work and adaptation to new conditions where a worker performs[1]. If a work is limited to only few permanent motions, that is group of muscles, fatigue occurs as consequence of static strain of the muscles if extremities of a body are immobile. Due to long-term compulsory postures of the upper body part, extremities and head, and increased general muscle tonus, muscle-bone problems as well as spine problems occur although such working posture can be classified as easy according to the criteria of energy consumption.

Damages and degenerative changes of bone-joint structures are consequence of discordance between requirement for organism burdening and organism possibility to react to these requirements[2, 3]. Psychic disturbances, such as general fatigue, slowness and exhaustion are frequently related to unsuitably formed work place in relation to a worker, that is negligence of application of ergonomic principles while forming a work place[4].

At the existing work place the biggest worker's strength is when levers on work table are situated at height of worker's shoulder. For determination of body postures, corresponding reactions in workers muscles and bone system occur, and specially in abdominal area, which reacts by increase or decrease of inner pressure. The inner pressure acts forward towards abdominal muscles, backwards into the spine and lumbal muscles, upward towards diaphragm and downwards towards the bottom of pelvis. The effect of forces of the inner pressure in a man who lifts burden, in skeletal presentation is given in figure 1.

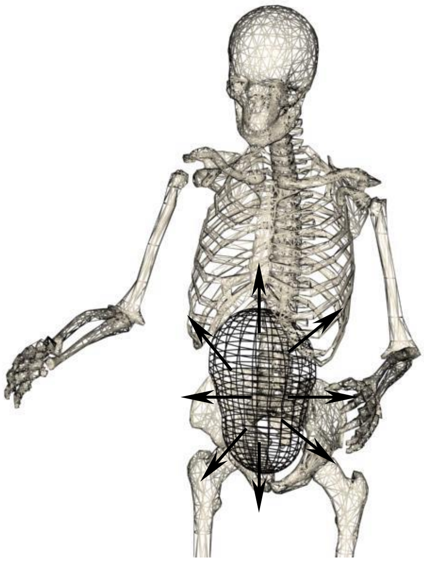

Fig. 1. Presentation of intraabdominal pressure in a man lifting weight

While forming the total working space in accordance with total criteria of the standing posture, it is necessary to know anthropometric characteristics of a worker. Dimensioning of a work area should be put in accordance with anthropometric sizes of a worker. Rudan[5] states anthropometric sizes for men with average value of the total height of 175 cm and limits of 163 cm up to 187 cm, and for women with values of 165 cm and limits of 153 cm up to 177 cm. Muftić[6] points to the methods of harmonic anthropometrics as base for applied dynamic ergonomy. In that process it is assumed that during implementation of certain task individual parts of human body do not function independently one from the other, but as functional wholeness.

By introducing computers and computer 3D program solutions a prototype can be replaced by 3D models where it is possible to carry out interactively all necessary forming and changes in real time. Computer 3D model used for the purpose of testing should be versatily studied and checked, since otherwise each its deficiency would be found in all realized final elements of the implemented project. Making of biomechanic model of human body requires thorough preparation and analysis of each individual segment from which human body consists[7]. This means that authenticity of presentation of human body depends on in advance defined number of sections, at which process segments of human body should be divided to smaller parts. In forming segments of body symmetry of body building is assumed in order to get symmetrical value of burdening for left and right extremities.

Biomechanical mechanism of movement of a man are very complicated and demanding and thus most frequently during analysis of branching of building entities and synthesis of movement when it is necessary to define simultaneously mobility and managing of researched system in more narrow sense that is group of system in a wider sense. Structure scheme of men's skeleton has very large number of degrees of movement freedom. Since man's skeleton contains; 95 joints with one level of movement freedom, 80 joints with two levels of movement freedom and 75 joints with three levels of movement freedom and this in total gives 250 levels of movement freedom, complete complexity of kinematic and dynamic research of man's skeleton is understood. This is important since movability of computer 3D character depends on the number of levels of movement freedom of its building elements.

In human organism none of the properties is constant for certain longer period of time. Human body consists of heterogeneous material and all its and its properties are different for various parts. Sex of a man is also very important factor during modeling of computer 3D character. During modeling of segments of women body by geometric bodies it is necessary to introduce hypothesis and simplification, this means that in the area of breast and hips it is necessary to widen trunk in relation to the appearance of male body[8].

On the basis of inner kinematic model of human body outer kinematic model is being made which presents muscle system of the body, where inner kinematic model is used as base for construction. By computer even the most complex movements of 3D character consists of various basic movements in its individual parts and in individual joints similarly as in locomotor system of a man. Human body can be presented within computer 3D analysis as system of shafts and corresponding forces which are its moving parts (muscle in a man). In this process forces towards the shafts, that is muscles towards the bones, acts as on shafts and center of rotations are in joint shafts and towards force of gravity represent forces of opposite direction.

Human skeleton can be considered as a group of one closed kinematic chain (spine with rib cage/thorax) and five open kinematic chains (head, arms and legs). Two kinematic chains, closed, spine with rib cage and open, right arm, were analyzed in this work. In order to enable scientific visualization and analysis of lower and upper arm movement of a worker, it was necessary to include also all other kinematic chains which are composite building elements of computer 3D character along with spine with thorax/rib cage and right arm of a worker on working postures.

Problems of adaptation of work of a worker is considered by the analysis of static and dynamic burdening during work, and in this process groups of most favourable postures of body and extremities during work are investigated. Thus fatigue is reduced which occur by active work of muscles and because of strained attention and this is frequent case in industry.

In ergonomically functionally studied and implemented working postures or working environment, where a worker carry out his work, accordance of static and dynamic burdening of human body is attained and fatigue which occurs because of active use of muscle is reduced. Working postures should be such as to enable change of postures within the limits in which a worker redistribute his weight during work, not changing his general working postures. Current research show that ergonomically functionally studied working postures and working environment, facilitates working effect and prevent fatigue, slowness, exhaustion and permanent reduction of worker's working capability.

Theoretical part

A worker cannot take correct or wrong postures while standing, but standing can be either comfortable or uncomfortable. Standing with equal burdening on two legs is optimal postures for the spine and specially for its lumbal part. Adverse postures of a worker is manifested through increased coefficient of tiredness because of overcoming of burden at corresponding body postures. Those unfavourable postures can be professionally dangerous where burdening of the spine are excessive and are at the edge of physiologically accepted sizes[9].

At standing postures a worker frequently rotate rib cage that is bent the lower back, so it is bent in hips. Intraabdominal pressure acts within abdominal cavity and support neighbouring lumbal vertebra causing fiber strain which partially alleviate compression of the spine. During bending forward also nucleus pulposus is moved forward and during bending backwards also nucleus pulposus travels backwards. Pressure on spinal cord (if deformation exists) will increase during bending backwards. Figure 2 represents biggest mobility of the spine forward and sidewise.

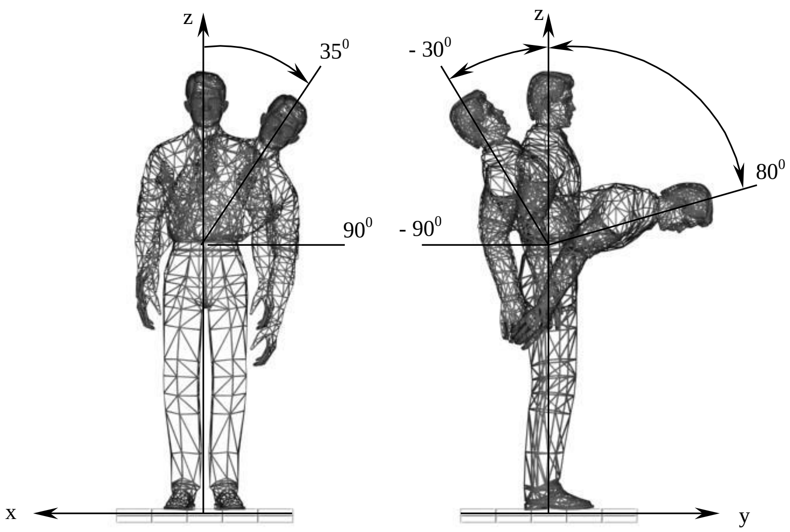

Fig. 2. The biggest angle mobility in spine joints forward and sidewise

Motion between spine joints is realized through intervertebral disc and direction and scope of motion through small joints. Motion between spine joints is realized through intervertebral disc and direction and scope of motion through small joints. Pressure force effected on the trunk during various tasks cause increase of pressure in abdominal cavity. Pressure is distributed on diaphragm and downwards on pelvis, on breast part of spine and pelvis muscles[10]. According to results of Mairiaux at. al.[11, 12] intraabdominal pressure IAT (kPa) depends on lumbal moment M_L (N m) at the level of lumbal spine L4/L5 vertebrae and is calculated according to:

$$IAT = 0.079\ M_L - 1.127\ \text{kPa} \qquad [1]$$

where:

IAT (kPa) : intraabdominal pressure,
M_L (N m) : lumbal moment.

The surface of the model of abdominal section and other sizes according to figure 3 are calculated according to Muftić and Jurčević-Lulić[10] by means of:

$$S = (\ 86.5 \ \text{to} \ 104.72\ )\ 10^{-4}\ h^2\ m^2 \qquad [2]$$

$$AD = \frac{h}{8} \qquad [3]$$

$$\frac{AB}{2} = \frac{CD}{2} = \frac{h}{36} \qquad [4]$$

$$BC = FE = \frac{h}{72} \qquad [5]$$

where:

S (m^2) : total surface of section of abdomen,
h (m) : body height,
AD (m) : length of complete lumbal area,
AB (m) : length of left lumbal area,
CD (m) : length of right lumbal area,
BC = FE : length of umbical area.

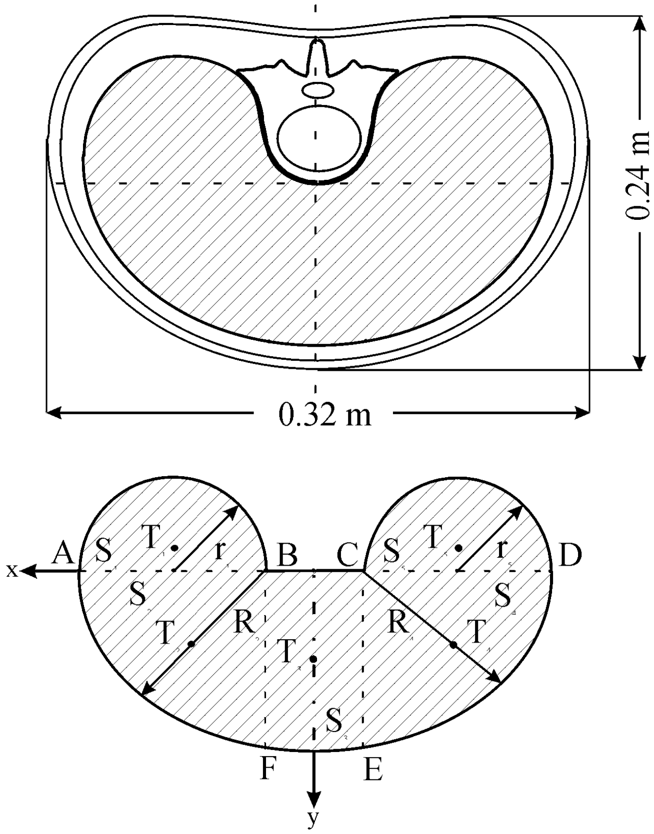

Fig. 3. Section through the abdomen with marked areas

Total area where intraabdominal pressure is applied is calculated by means of:

$$S = S_1 + S_2 + S_3 + S_4 + S_5 \qquad [6]$$

where:

S (m^2) : total area of abdominal section,
$S_1 = S_5$: areas of abdominal section,
$S_2 = S_4$: areas of abdominal section,
S_3 : areas of abdominal section.

For different workers heights (h) it is possible to calculate total section area in the field of abdominal section (S) on which intraabdominal pressure is applied. According to Morrisu[13] pneumatic mechanism should be reduced by 30% calculated on compressive force. Davis & Stubbs[14] propose that in work where intraabdominal pressure is 13.07 kPa and even more, increase of spinal damage occurs.

Experimental part

Anthropometric sizes of a worker during forming of working area

Determination of anthropometric measures in conventional way is complex and longstanding. Introduction of new computer methods enables quick and accurate determination of all important body sizes so that dimensions and shapes of elements of environment are adapted to a man. In respect of that computer program has been developed which with incoming data of sex and body heights of people, establishes twenty two characteristic anthropometric sizes. Figure 4 represent screen review of position characteristic, computer obtained anthropomeasures of a 195-cm man.

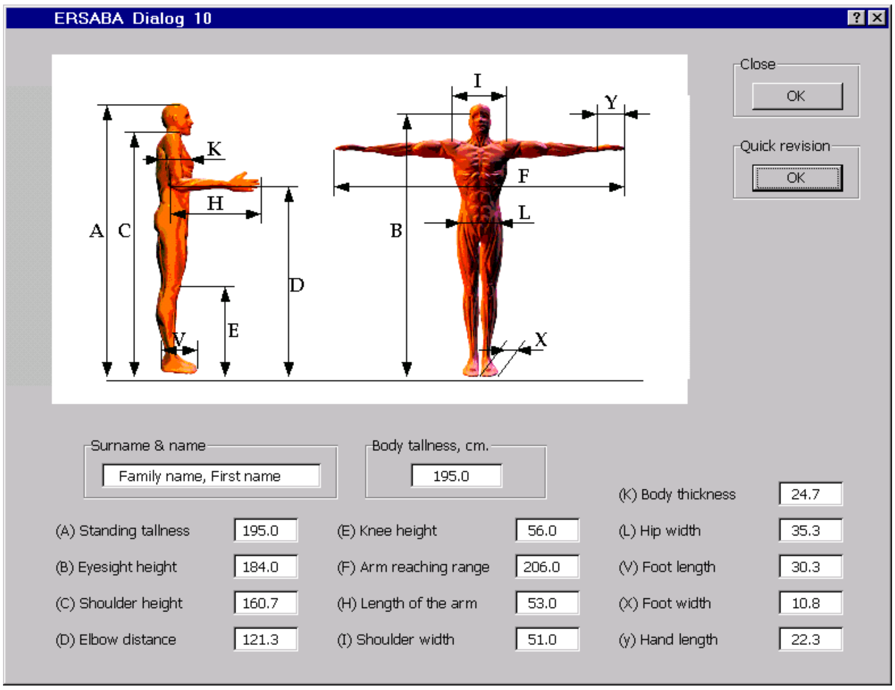

Fig. 4. Screen review of characteristic anthropometric measures for standing position

Table 1 represents characteristic anthropometric measures for separated cases of women of 160,0 cm, 170,0 cm and 180,0 cm, and men of 165,0 cm, 180,0 cm and 195,0 cm.

Table 1.
CHARACTERISTIC ANTHROPOMETRIC MEASURES
OF MALE AND FEMALE WORKERS IN STANDING POSITIONS

Marking and name of anthropometric measure		Anthropometric measures (cm)					
		Male			Female		
		I	II	III	I	II	III
A	Standing tallness	165,0	180,0	195,0	160,0	170,0	180,0
B	Eyesight height (standing)	154,8	169,0	184,0	149,4	158,6	167,8
C	Shoulder height (standing)	135,7	148,2	160,7	129,8	138,2	146,5
D	Elbow distance from the floor	102,2	111,3	121,3	99,7	106,3	113,0
E	Knee height (standing)	47,7	52,3	56,0	47,8	50,7	54,0
F	Arm reaching range	175,2	191,0	206,0	160,0	170,0	180,0
H	Length of the arm from the elbow (including hand)	44,7	49,3	53,0	41,8	44,3	46,8
I	Shoulder width	42,7	47,3	51,0	38,8	40,8	42,5
K	Body thickness (chest)	21,3	23,4	24,7	24,2	25,8	27,5
L	Hip width	29,5	32,8	35,3	33,2	35,3	37,8
V	Foot length	25,3	27,8	30,3	24,2	25,8	27,5
X	Foot width	9,6	10,2	10,8	8,8	9,2	9,6
Y	Hand length	18,2	19,8	22,3	16,9	17,9	18,8

On the basis of human height, weight and sex and necessary preciseness of work and posture during work it is possible from the point of ergonomy to determine precisely dimensions of ideally formed space for each individual worker. Calculation results in this work have only been taken for male subjects. Being informed on anthropometric measures and by application of computer equipment and computer 3D graphic programs it is possible to implement ergonomic modeling of dimensions and elements of environment very effectively and quickly so that they can be adapted to a man. In order to determine relation in dimension between a man and machine recording by camera of a worker on steam pressure for final ironing of a cuff Schödt & Krebs GmbH, model X – G – 36 was carried out with this work.

The stated machine has been presented on figure 5.

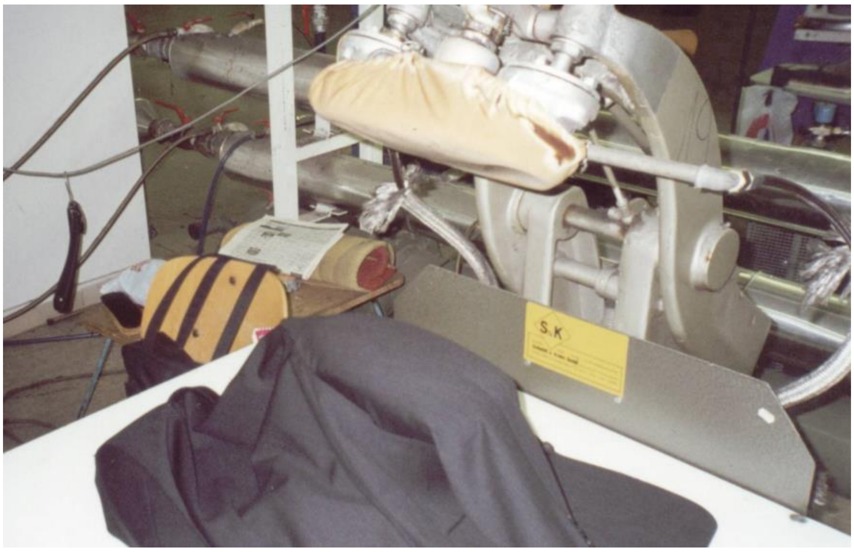

Fig. 5. Pictural review of an iron for final cuff ironing

3D visualization

3D modeling, design, animation and scientific visualization of this work was made on high-end workstation with use of various 3D graphic - animation programs. On the basis of recorded worker and working posture in the manufacturing process, computer model of 3D work, machine and working posture was made. Received computer 3D model has been compared and put in accordance with realistic model of working posture and a worker. According to realistic data on received 3D scene biomechanic analysis of working motions of workers bodies was carried out by scientific visualization. 3D model of a worker, machine and working posture make 3D scene under which in computer graphic oriented part of space is understood to which coordinated system is merged in relation to which posture and orientation of entity, primitive, objects or their group. On the basis of these parameters dynamic anthropomeasures are calculated which are used as basis for simulation character animation showed on figure 6.

Figure 6 represents perspective frame in wire review of simulation model of a worker on working posture. Wire review of a model describes certain object by lines, circles, and arches that represent edges of objects. Geometric form within computer 3D graphic program may be defined; a) editable mesh which can be represented as vertex, edge, face, polygon or element, b) editable patch which can be presented as vertex, edge or patch and c) as NURBS surface. Accessible coordinators within original/authentic coordinate system determine geometric form.

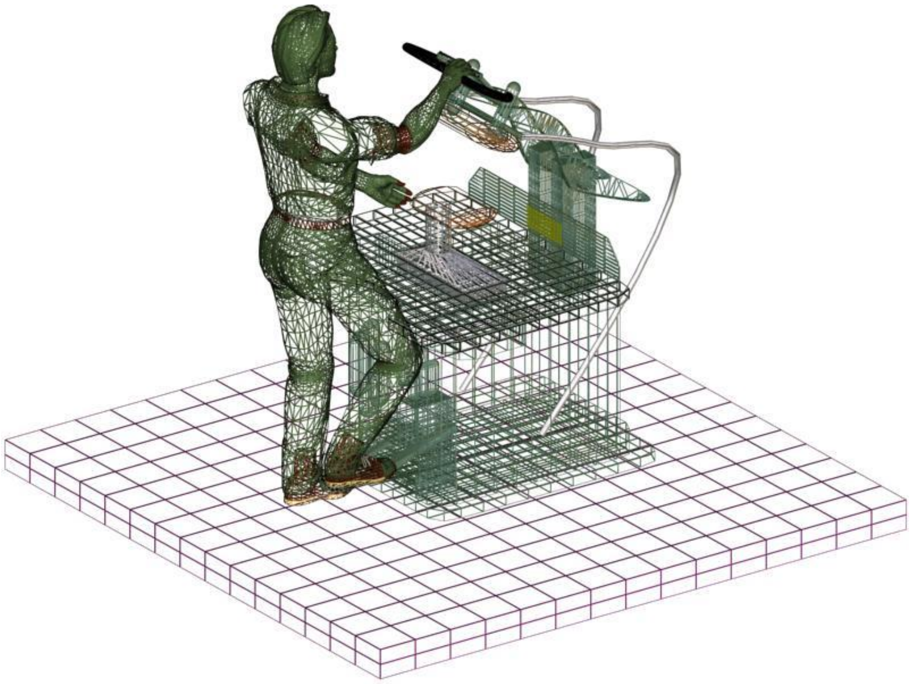

Fig. 6. Perspective wire review of simulation model of a worker on work place

By use of existing realistic or computer made maps and materials and analysis of its parameters like; Ambient Color, Diffuse Color, Specular Color, Glossiness, Self–Illumination, Opacity, Bump, Reflection, Refraction, etc. it is possible after implementation of more complex procedure of rendering to obtain very realistic that is photo–realistic results of virtual space of working posture that is a worker. Photo-realistic analysis of frame (figure 6) of perspective wire review of simulation model of a worker on working posture new frame was obtained with presentation on figure 7. Proportion and view of a camera on simulation worker model and worker posture on figure 7 remained the same as on figure 6 in respect of observation of possible differentiation of the final review of the one and the same frame with maintenance of the same proportions and view of camera. Individual elements, group of elements, frame or complete visualization with stated and presented wireframe and photo realistic review can be made also in the following reviews; Cartoon, Carton Wire Line, Flat Lined, Flat shaded, Hidden Line, Lit Wireframe, Outline, Sillouette, Smooth Lined, Smooth Shaded, Texture Shaded etc.

Fig. 7. Perspective computer photo-realistic review of simulation model of a worker on working posture

In dependence on the change of burdening of the machine its operating possibilities are calculated and worker engagement operating the machine depends on that. In the stated steam pressure for final cuff ironing (pictorial review on figure 5, perspective wire review with included working posture of a worker figure 6 and computer photo-realistic review figure 7) one portion of operation is done manually.

Before a worker begins to work his position is under the pressure. A worker position of a subject on the lower part according to the technological purpose formed pedestal for ironing and then he moves the upper part of the pressure downwards and this results in hold of chosen part of the cuff by upper and lower ironing object. In dependence with technological requirements of processing a worker holds the upper part of the pressure for certain time maximally closed. Following that operation he returns the upper part of the pressure in the initially maximally opened position and by putting of the piece of manufacturing at the place which is predicted for that he finishes the working operation.

Within the stated a worker can by combined motions of legs and arms determine time, intensity and duration of steam and vacuum on the article of clothing. Sequence, frequency and scope of operation are conditioned by technological process.

Results

Two-dimensional working posture of a worker in sagital plane put in coordinated system with burdening (weights of body parts and weights of G working parts of the machine) and forks during lifting of the upper parts of a machine more simplified kinematic pair in which reference position of vertebrae L4/L5 in the starting point is O, have been shown on figure 8.

The upper part of a worker with inserted positions of burdening of body parts, was burdened with forces F_1 up to F_7 which cause lumbal moment. During standing the pressure force within the disc is from 785 up to 980 N. The force in the disc during bending increases to 1470 N, and during lifting or transferring of the burden may be up to 9807 N (Mairiaux at. al.[11, 12]).

For a worker in the upper part of burdening by weights of corresponding parts of body and G working part of a machine (figure 8), and its forks and moments, a lumbal moment M_L = 150.41 N m was determined, and intraabdominal pressure IAT = 10.76 kPa is its result. This value IAT = 10.76 kPa is satisfactory since it is lower than the allowed values 12 kPa[10].

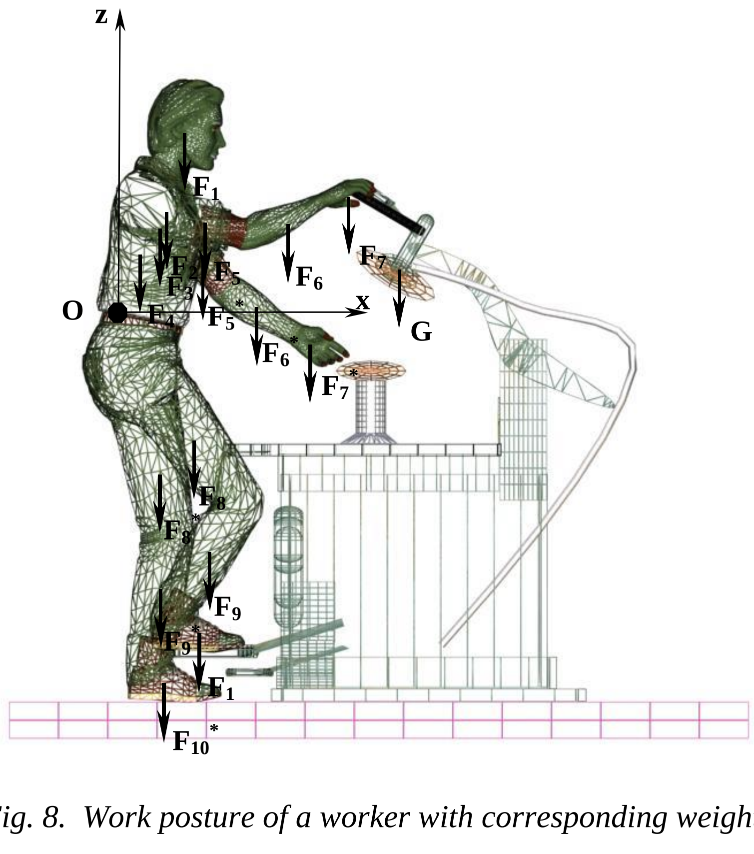

Fig. 8. Work posture of a worker with corresponding weights

Weights of corresponding parts of worker's body of 165 cm body height weighing 740 N and G of working part of a machine, and its distance from lumbal vertebrae L4 and/L5 and lumbal moment obtained by multiplying of weights and distance have been stated in table 2.

Table 2.
WEIGHTS OF CORRESPONDING BODY PARTS AND G WORKING PART OF A MACHINE IN SAGITAL PLANE IN DEPENDANCE WITH ARM SHIFT

Marking	Part of worker's body and G of machine	Weight F (N)	Distance a (m)	Lumbal moment F x a (N m)
1.	Head and neck	51.36	0.06	3.08
2.	Upper part of trunk	118.07	0.09	10.63
3.	Middle part of trunk	120.82	0.07	8.46
4.	Lower part of trunk	82.69	0.04	3.31
5.	Right upper arm	20.03	0.12	2.40
5.*	Left upper arm	20.03	0.09	1.80
6.	Right lower arm	11.96	0.41	4.90
6.*	Left lower arm	11.96	0.26	3.11
7.	Right fist	4.54	0.55	2.50
7.*	Left fist	4.54	0.44	2.00
8.	Right upper leg	104.82	0.22	23.06
8.*	Left upper leg	104.82	0.12	12.58
9.	Right lower leg	32.04	0.22	7.05
9.*	Left lower leg	32.04	0.12	3.84
10.	Right foot	10.15	0.16	1.62
10.*	Left foot	10.15	0.14	1.42
11.	G of machine	85.00	0.69	58.65

Sum lumbal moments $M_L = \sum_{i=1}^{7} F_i \cdot a_i = 150.41$ N m

$IAT_M = 0.079\, M_L - 1.127 = 10.76$ kPa

On the basis of burdening by weights of corresponding body parts (forces), and its extremities and moments the lumbal moment was determined M_L = 150.41 N m, where from the intraabdominal pressure IAT_M = 10.76 kPa results which is within the permitted limits (up to 13 kPa for men[13]).

Activity of a men is related to the corresponding working burdening and thus with strain. Burdens, which occur in man's work, are frequently connected to his non-ergonomic posture. Non-ergonomic posture of workers body is harmful and especially if it is compulsory.

Description of human body's motion is done in various ways in dependence on requirements for which they are made. Three characteristic working postures that is frame are separated within animation, in dependence with motion of an arm of a worker and upper part of a machine and thus as; maximally opened $\upsilon = 0^0$, maximally closed $\upsilon = -30^0$ and interposture $\upsilon = -15^0$ with presentations in sagital plane.

Figure 9 represents 3D wire model of a worker with body height of 165 cm, in the upper part of the figure of erect closed kinematic chain where angle of trunk slope axis is $\varphi = 0^0$, and in the lower part of figure for angle of dip is $\varphi = 8^0$ trunk slope according to position of operating part of a machine.

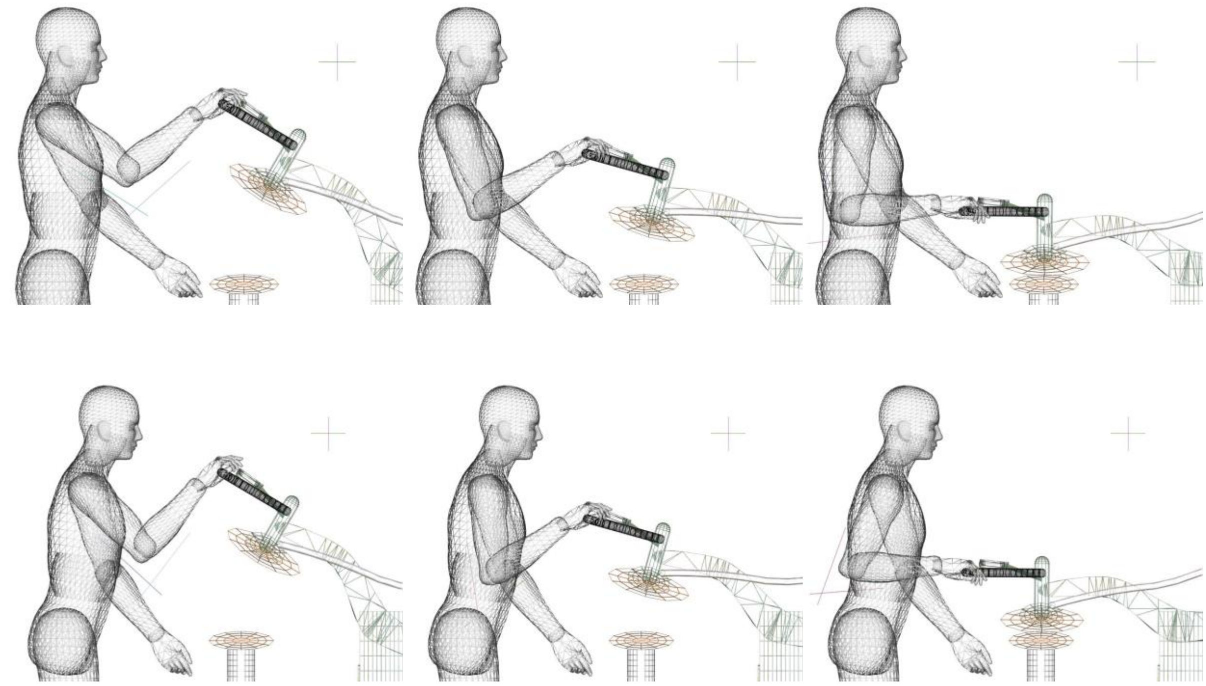

Fig. 9. 3D wire review of characteristic postures during visualization of work of a worker with body height of 165 cm

Rotation angles and arm translation have been determined on the basis of upper and lower arms of a worker, with review of received results in table 3 for a worker with body height 165 cm, in table 4 for a worker with body height 180 cm and in table 5 for a worker of body weight 195 cm, in this process angle α between vertical axis and upper arm, and angle β is angle between horizontal axis and lower arm. Direction of watch-hand is taken as positive value of an angle and negative value of an angle is direction opposite to the motion of watch-hand.

Table 3.

ANGLE SLOPE OF UPPER AND LOWER ARM IN RELATION TO VERTICAL AND HORISONTAL AXIS OF A WORKER OF 165 CM BODY HEIGHT

Working posture of a worker of 165 cm height	Working posture of a machine					
	Maximally opened ($\upsilon = 0^0$)		Inter posture ($\upsilon = -15^0$)		Maximally closed ($\upsilon = -30^0$)	
	Angles of upper arm α (^{0}) and lower arm β (^{0})					
	α	β	α	β	α	β
$\varphi = 0^0$	- 58	- 43	- 22	- 33	+ 02	- 07
$\varphi = 8^0$	- 48	- 51	- 10	- 37	+ 20	- 08

According to the results from table 3 and figure 9 in erect posture the smallest angles are obtained *α and β* at maximally closed working position of a machine and at maximally closed position of a machine, and biggest at maximally opened.

During dip of a trunk by $\varphi = 8^0$ in relation to erect axis angle of upper arm is reduced α

and lower arm angle is increased β.

Figure 10 represents 3D wire model of a worker with body height of 180 cm., where working postures as on figure 9 are taken.

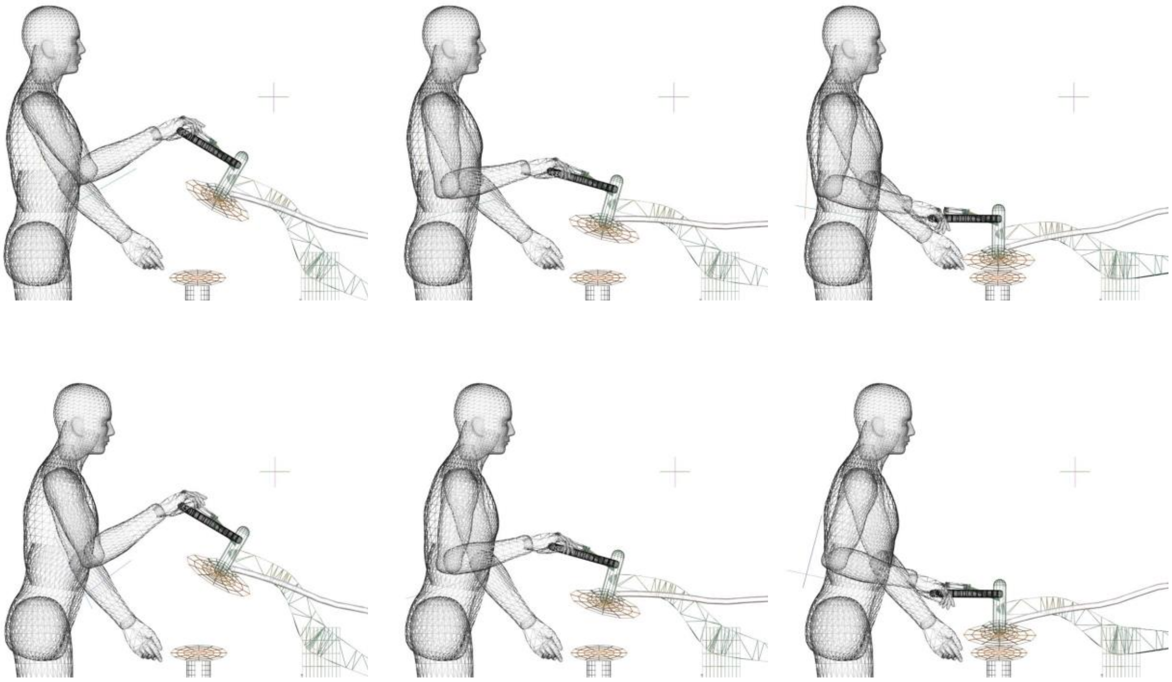

Fig. 10. 3D wire presentation of characteristic postures during visualization of work of a worker with body height of 180 cm

Table 4.

ANGLES OF SLOPE OF UPPER AND LOWER ARM IN RELATION TO VERTICAL AND HORISONTAL AXIS OF A WORKER WITH BODY HEIGHT OF 180 CM

Working posture of a worker of 180 cm height	Working posture of a machine					
	Maximally opened ($\upsilon = 0^0$)		Inter posture (υ = - 15^0)		Maximally closed (υ = - 30^0)	
	Angles of upper arm α (^{0}) and lower arm β (^{0})					
	α	β	α	β	α	β
$\varphi = 0^0$	- 41	- 30	- 10	- 18	+ 03	+ 11
$\varphi = 8^0$	- 28	- 37	+ 01	- 19	+ 15	+ 10

According to table 4 and figure 10 lower values are obtained α and β in relation to figure 9 and this is connected with anthropometric sizes and results in machine construction getting closer to anthropometriic measures of a worker.

In all postures angle α is reduced, and angle β is increased.

3D wire model of a worker with body height of 195 cm with working postures as on figures 9 and 10 are presented on figure 11.

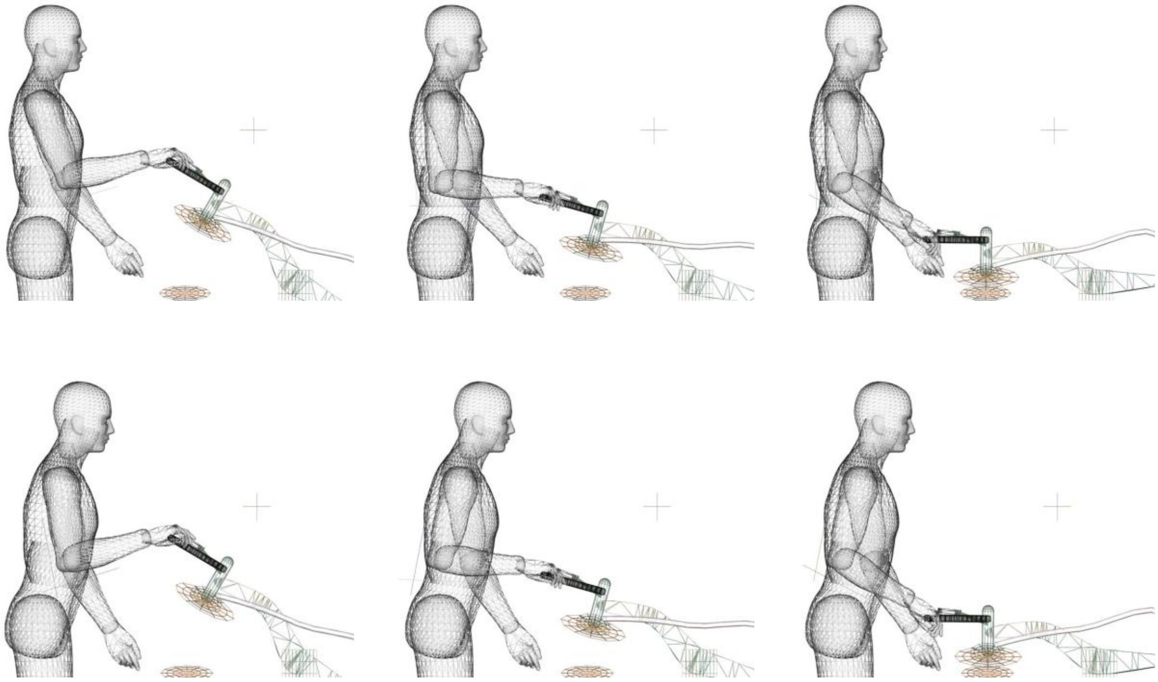

Fig. 11. 3D wire presentation of characteristic postures during visualization of work of a worker with body height of 195 cm

Table 5.
ANGLES OF SLOPE OF UPPER AND LOWER ARM IN RELATION TO VERTICAL AND HORISONTAL AXIS OF A WORKER WITH BODY HEIGHT OF 195 CM

Working posture of a worker of 195 cm height	Working posture of a machine					
	Maximally opened ($\upsilon = 0^0$)		Inter posture ($\upsilon = -15^0$)		Maximally closed ($\upsilon = -30^0$)	
	Angles of upper arm α (^{0}) and lower arm β (^{0})					
	α	β	α	β	α	β
$\varphi = 0^0$	- 26	- 16	- 03	+ 03	- 03	+ 27
$\varphi = 8^0$	- 11	- 18	+ 10	+ 01	+ 11	+ 26

According to table 5 and figure 11 equal angle α is obtained for working inter position and maximally closed position of a machine in erect position of a trunk where $\varphi = 0^0$, for a worker with body height 195 cm. This is unfavorable for a worker since he has bigger burdening of upper arm.

With trunk dip by $\varphi = 8^0$ towards the working part of a machine angle α is increased and this results by increase of angle β .

Discusion and Conclusion

Introduction of 3D computer graphic in the analysis of biomechanic model of a worker should be conceived on the basis of data by means of which it is possible to study elements of model or complete model. On the basis of biomechanic method of defining worker's burdening, by use of anthropometric values of population and by calculating weights of individual parts of a body it is possible to determine size of forces and conjunctions for any points of a center of weight of worker's body. Using 3D model minimal and maximum rotations angles have been calculated and translations of upper and lower arm and thus shifts and burdening can be determined.

By application of such research of complete forming of work places and places for rest conformity of machine dimension and human body can be determined and correct posture during work, which reduce consumption of body energy to the least possible measure. Thus within the manufacturing process worker's fatigue is reduced, his work is humanized and productivity and quality of product is increased[15, 16].

Using computer made maps, material on the models and by analysis of parameters of the model it is possible to get photo-realistic results of worker's model and virtual environment by rendering. Thus optimal dimensions of the machine and environment can be obtained in respect of optimal utilization [17, 18].

On the basis of the received measurements results angles of rotation and traslations of worker's arm at certain spine posture have been analyzed. According to the results presented on figures 9,10 and 11 ergonomic position of a worker during work can be evaluated.

According to the tables 3, 4 and 5 with maximally opened working position of a machine ($\upsilon = 0^0$) the highest angles of rotation and upper arm and translation of lower arm at bend working position for $\varphi = 8^0$ are in a worker with body height of 165 cm, and lowest in worker of body height 195 cm. With maximally closed working position of a machine ($\upsilon = -30^0$) a worker with body height of 180 cm has the most favourable position at work. On the basis of results presented on figures 9, 10 and 11 rotation of upper arm and translation of lower arm can be evaluated at erect position of the body using in this process results from tables 3, 4 and 5. In working position of a worker where trunk dip $\varphi = 8^0$ towards the operating part of the machine, according to tables 3, 4 and 5 angle of upper arm α is reduced and angle of lower arm β increased. The size of angle change α and β depends on anthropometric measures of workers and is visible on considered realistic and computer 3D modeled and scientifically visualized worker with body height of 165 cm, 180 cm and 195 cm.

The results that values of curving angle of the upper arm and translation of the lower arm are different in workers and this show that they depends on technological process. On the base on this it can be evaluated that also burdening of workers in technological process of clothes ironing differ.

Minimal and maximum rotation angles and translation of working posture of arm depend on change of burden of a machine. Determination of working space has special importance in defining of working area in this example, under which term a working surface where manual activities are performed are understood.

Working position should be such as to enable change of posture within the limits where a worker redistribute his weight during work not changing his general working position. Better forming of work place, correct posture and holding of body trunk and technical equipping of machines, burdening in the lumbal part of spine will be reduced. The purpose is to maintain body posture and biomechanic more correct movement and in this process skill should be used more than strength.

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S A Ž E T A K

U radu je provedena računalna 3D vizualizacija radnog mjesta pomoću računalno izvedenog 3D modela stroja i računalske karakterne animacije radnika. Vizualizacijom 3D karaktera u iverzno kinematičkoj i dinamičkoj vezi sa upravljačkim dijelom stroja određene su biomehaničke značajke tijela radnika. Za utvrđivanje dimenzija stroja proveden je uvid u tehničko - tehnološku dokumentaciju stroja, izvršena je radna izmjera stroja i provedeno je snimanje kamerom, dok se antropometrijska mjera tjelesne visine radnika utvrdila mjerenjem. Na osnovu izmjerenih tjelesnih visina, pomoću računalnog programa razvijenog od strane autora određene su sve relevantne antropometrijske veličine radnika. Poznavanjem antropometrijskih mjera, vidnih polja i zona dosega pri oblikovanju radnih mjesta utvrđeni su točni položaji radnika pri izvođenju tehnoloških postupaka. Pri tome su analizirani minimalni i maksimalni kutevi rotacija i translacija nadlaktice i podlaktice koji su baza za izučavanje opterećenja radnika. Računalnom antropometrijskom analizom pokreta dobivene su dimenzije zahvatnog prostora tijela, kao npr. dohvati ruku, položaji nogu, glave, leđa itd. Razmotreni su

utjecaji oblikovanja radnih mjesta na pravilan položaj radnika pri radu, čime se njegov utrošak energije i zamor svode na razmjerno mali iznos.