293. Determination of rational sizes of leg prosthetics manufacturing errors and their links resilience

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Abstract. Paper presents rational values of manufacturing and assembly summary errors appointed according to hip and its joint, knee and tarsus motion trajectories, angular analysis, also research results of step asymmetry and variation of shoulder's and head's tilt angles, either the anthropometrical parameters were evaluated. The analysis of possibilities of manufacture and assembly errors and inter-compensation of leg prosthesis elastic links was made. The results showed that disabled person gait will be smoother and he will not get tired so soon, when values of elastic deformations will be two times bigger than the summary value of manufacturing and assembly errors. Besides, the essential condition of disabled smooth gait is that the value of manufacturing and assembly errors of leg prosthesis links would be positive.

Keywords: manufacturing errors, elastic deformations, inter-compensation, leg prosthesis, locomotion.

Introduction

The center of gravity during human gait moves by particular angle to the left or to the right periodically removing it on the left and the right leg. Lengths of legs of disabled person with one prosthetic leg could be unequal. This is caused by leg prosthesis manufacturing and assembly errors and also elastic deformations of prosthetic links acting on the person walk. Therefore the gait of disabled person becomes unsmooth and he gets tired sooner. The smoothness of human gait and its parameters has been researched by many scientists [1, 2, 3, 4, 5]. However, there is not much scientific works in the literature where influences of prosthesis links manufacturing and assembly errors, and elastic deformations on the motion and on the magnitude of the legs joints loading are analyzed. The works [6, 7, 8] present research of the influence of manufacturing, assembly, the receiver fixation to the stump errors on elastic deformations of prosthesis links. Unfortunately, inter-compensation between errors and elastic deformations, and possibilities of gait smoothness improvement are not analyzed enough. Thus, aims of this paper are to appoint rational values of manufacturing and assembly errors by theory and experimental ways and to analyze possibilities of inter-compensation between errors and links elastic deformations.

The Method of Investigations

The influence of prosthesis links manufacturing and assembly errors on the disabled person's gait smoothness has been researched by experimental way. The system of modern camera with three dimensional view and *SIMIVidback* software were used for the experiments. Legs lengths were varied in 3 till 40 millimeters. There were measured the asymmetry of the step, the trajectory and velocity of tarsus motion regarding $0X$ axis, the asymmetry of knee motion regarding $0Y$ axis and its velocities in point of $0X$ axis. Item, tarsus motion trajectory in point of $0Y$ axis, hip joint velocity, shoulder motion trajectory according $0Y$ axis and its velocities by $0X$ axis have been defined. Additionally, head motion trajectory and other important parameters which characterize the gait smoothness of disabled person have been appointed. Analyzing dependencies presented in figures 1, 2, 3 and 4, and summarizing other dependence from experimental data of disabled person gait smoothness parameters on prosthesis manufacturing and assembly errors, it has been noticed, that the elongation of the leg has a big influence on the asymmetry of a step and same on the hip and tarsus motion trajectories.

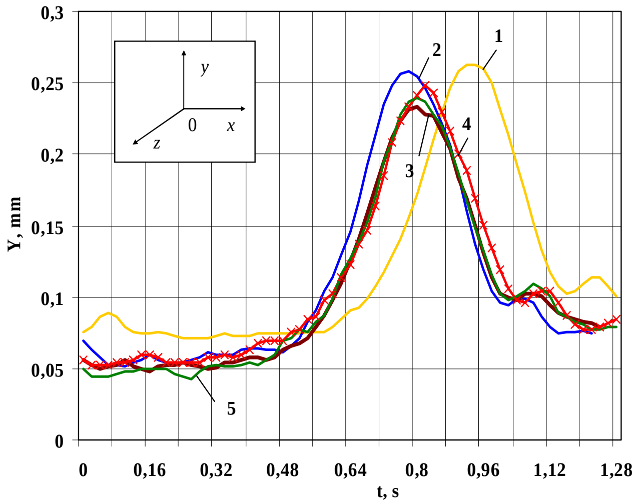

Fig. 1. The trajectory of tarsus motion according *0Y* axis, when *H = 1.75* m: 1 – legs have the same length, 2 – elongation of prosthetic leg 12 mm, 3 – elongation of prosthetic leg 24 mm, 4 – elongation of prosthetic leg 30 mm, 5 – elongation of prosthetic leg 39 mm

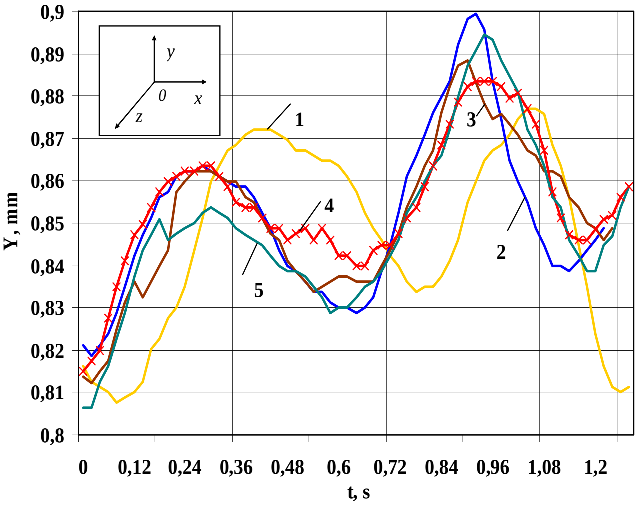

Fig. 2. The trajectory of hip motion according *0Y* axis, when *H = 1.75* m: 1 – legs have the same length, 2 – elongation of prosthetic leg 12 mm, 3 – elongation of prosthetic leg 24 mm, 4 – elongation of prosthetic leg 30 mm, 5 – elongation of prosthetic leg 39 mm

It is seen from Fig. 2 that, if person's both legs have the same length the height of hip joint motion approximately is the same – about 0.88 m.

Furthermore, when the prosthetic leg lengthen from 12 to 15 millimeters, the hip joint of it comes up till 0,9 m. Consequently, it is true to say that the hip joint of prosthetic leg goes up about 2 cm over other sound leg. Besides, under the leg elongation the person's stand is turning more to the one side and is less stable. If the prosthetic leg elongation about 12 mm its velocity at the leg removing phase increases very slightly. But under prosthetic leg elongation about 39 mm – the velocity in above mentioned phase declines. Noticed, that the value of velocity if the lengthening of prosthetic leg is from 24 mm to 30 mm varies less than in the case of 12 mm prosthetic leg elongation. So it must be said that there is no influence to gait velocity in the way of prosthetic leg elongation till 24 mm.

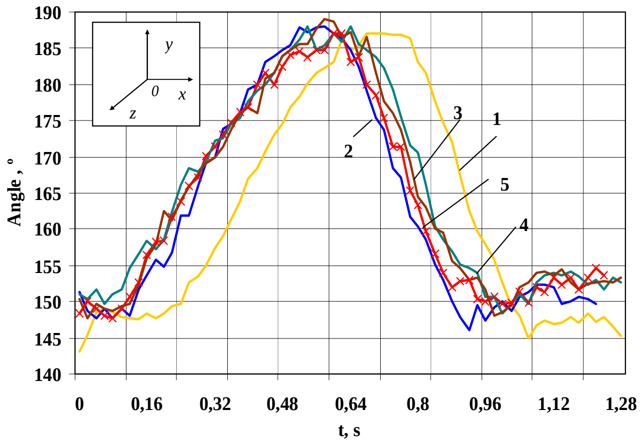

Fig. 3. Angles of hip joint motion in degrees, when *H = 1.75* m: 1 – legs have the same length, 2 – elongation of prosthetic leg 12 mm, 3 – elongation of prosthetic leg 24 mm, 4 – elongation of prosthetic leg 30 mm, 5 – elongation of prosthetic leg 39 mm

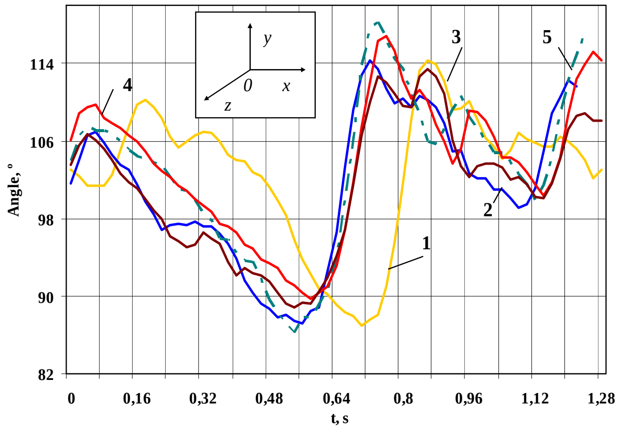

Fig. 4. Angles of tarsus joint motion in degrees, when *H = 1.75* m: 1 – legs have the same length, 2 – elongation of prosthetic leg 12 mm, 3 – elongation of prosthetic leg 24 mm, 4 – elongation of prosthetic leg 30 mm, 5 – elongation of prosthetic leg 39 mm

It has been determined that angles of joints of a hip and a tarsus are varying a little in the gait of disabled person with prosthetic leg.

The curves in the Fig. 3 show the development of hip bending angle in the asymmetry of a step and even a little elongation of prosthetic leg make an influence to additional motion of the hip joint. The leg lengthening is significant to bending of tarsus joint too as seen from Fig. 4. It has been determined, that the bigger load is taken to the longer leg and the joint turns by the major angle, and the tarsus joint bends to the interior. Therefore, the disabled person needs more efforts to keep the balance of the gait.

It has been noticed, during the research, that estimating trajectories of hip and tarsus joints and other variations of other unsmooth gait parameters on the walk with prosthetic leg, rational values of manufacturing and assembly errors could be expressed by such a proportion:

$$S \approx {}^{K_S}\!/_{H}; \; K_S = K_{Sp} - K_{Sk}, \qquad (1)$$

where K_S stands for development of the height of the hip joint lift due to elongation of prosthetic leg, on the person's walk; H is the height of a person; K_{Sp} stands for the height of the hip joint lift on the walk with sound leg; K_{Sk} is the height of the hip joint lift on the walk with the prosthetic leg.

Calculation results have showed values of ratio S, which are the following $S \cong 0{,}0069 - 0.0086$.

On other hand, the works [6, 9] present the relation between the rational values of manufacturing and assembly errors and values of elastic deformations of leg prosthesis links:

$$|\delta| = 2|\Delta l_{\Sigma}|, \qquad (2)$$

where $|\delta|$ is the modulus of the value of elastic deformation of prosthetic links; Δl_{Σ} is the modulus of summary value of leg prosthesis manufacturing and assembly errors.

The scheme of rational location fields of manufacturing, assembling errors and segments elastic deformation is shown in the Fig. 5.

It is easy to notice, that asymmetry can appear in many possible variants of location of fields of manufacturing and assembly errors, i.e. when is not satisfied condition as follows:

$$\Delta l_{\Sigma} - |-\delta| \neq -\Delta l_{\Sigma}. \qquad (3)$$

Equation (3) shows, that disabled human should make symmetrical trunk movement regarding vertical axis during gait, only then is satisfied condition as follows:

$$\Delta l_{\Sigma} - |-\delta| = -\Delta l_{\Sigma}. \qquad (4)$$

Condition (2) shows, that the magnitude of leg prosthesis elastic deformations is 2 times bigger than its elongation of links because of manufacturing and assembly errors, so the body of disabled human would swing symmetrical regarding vertical axis, as summary location field of links deformation will be equal $\Delta l_{\Sigma} - |-\delta| = -\Delta l_{\Sigma}$ and summary elongation of leg prosthesis also would be equal Δl_{Σ}. In that case under (3) and (2) conditions, the rational condition of compensation of leg prosthesis of manufacturing, assembly errors and elastic deformations are described.

When the equation (2) is satisfied, then the body of disabled human will not be in vertical position, and in the initial position will be slightly bended to the right or to the left side proportionally to the linear magnitude Δl_{Σ}. But body will swing regarding symmetrically vertical axis during gait.

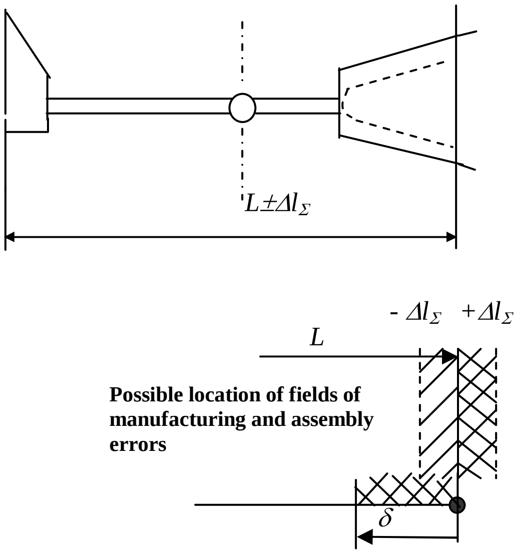

Fig. 5. The scheme of possible lay out of fields of manufacturing and assembly errors

Using calculation methodic presented in the works [6, 7, 8 and 9] and results of the research applied in this paper the table 1 of summary errors of manufacturing and assembly, and rational values of summary elastic deformations of leg prosthesis has been developed.

Data in the table 1 shows permissible values of prosthesis elongation $\Delta l_{\Sigma} \approx H \cdot S$, estimated evaluating variations of trajectories of disabled person pelvis, tarsus, knee joints, motion trajectories of shoulder and other body parts which have been got into intervals $\Delta l_{\Sigma\min}$, $\Delta l_{\Sigma\max}$ of summary values of manufacturing and assembly errors determined by other methods. It is important, that in all cases presented in the table 1 the conditions are $\Delta l_{\Sigma\min} < \Delta l_{\Sigma}$, and $\Delta l_{\Sigma} < \Delta l_{\Sigma\max}$. Thus, applying the requirements of $\Delta l_{\Sigma\min}$ for design and manufacturing of leg prosthesis, the enough stable disabled people's gait would be guaranteed. In the stages of leg prosthesis design and manufacturing the requirements of $\Delta l_{\Sigma\max}$ for summary values of manufacturing and assembly errors must be avoided. But the expression (2), which requested $|\delta| = 2\Delta l_{\Sigma}$, must be taken into account. It means, that in mentioned case, when one is designing small stiffness prosthesis, the elastic deformations $|\delta|$ will be big, and of course, the value of Δl_{Σ} might be enlarged for fulfilling the condition (2). Consequently, the disabled person gets tired very soon and if he uses the prosthesis for longer time, he will feel pain in the various parts of the body, especially in the waist and spine regions. So the scoliosis could appear.

Table 1.

Dependence rational value of manufacturing and assembly errors and elastic deformations of leg prosthesis on person‘s anthropometrical parameters, determined by different ways, when $|\delta| = 2\Delta l_\Sigma$

No	Person's anthropometrical parameters				$\Delta l_{\Sigma\min}$, mm	$\lvert\delta\rvert_{\min}$, mm	$\Delta l_{\Sigma\max}$, mm	$\lvert\delta\rvert_{\max}$, mm	$\Delta l_\Sigma \approx H \cdot S$, mm	$S \approx K_S/H$, mm
	H, m	*h*, m	*T*, m	*t*, m						
1.	1,0	0,57	0,06	0,06	2,64	5,28	12,56	25,12	6,9 – 8,65	0,0069 – 0,0086
2.	1,2	0,69	0,07	0,07	3,30	6,60	14,36	28,72	8,28 – 10,32	
3.	1,4	0,80	0,08	0,08	3,69	7,38	15,90	31,80	9,66 – 12,04	
4.	1,6	0,92	0,09	0,09	4,22	8,44	17,53	35,06	11,04 – 13,76	
5.	1,8	1,03	0,10	0,10	4,70	9,40	19,33	38,66	12,42 – 15,48	
6.	2,0	1,15	0,11	0,11	5,27	10,54	20,95	41,90	13,80 – 17,20	

Explanations of parameters presented in the Table 1: *h* – mass center height of disabled human, *T* – distance between standing person central lines; *t* – foot width.

Conclusions

Observing disabled person's motion trajectories of pelvis, tarsus, knee joints, their variations of velocities and the research results of his unsmooth gait, the following conclusions have been made:

- it has been determined, that the effect of manufacturing and assembly errors summary value could be estimated by the ratio of leg prosthesis elongation and persons height. When this ratio is in the interval 0,0069 – 0,0086 or less – the gait of disabled person will be sufficient;
- summary values of manufacturing and assembly errors always must be positive and their rational value depends on summary value of elastic deformations of links;
- it has been shown, that requirements of manufacturing and assembly errors summary values estimated evaluating variations of trajectories of disabled person pelvis, tarsus, knee joints, motion trajectories of shoulder and other body parts, are stricter and bind permissible maximal values of errors appointed by other methods.

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