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DYNAMIC ANALYSIS OF A SUGAR BEET LIFTER

Summary

In the paper presents the way of model 3D creation, stages of preparation as well as results of dynamic simulations of the sugar beet lifter. In the computer simulations kinematic input and assigned values of the forces acting on the lifter share were taken into account. The presented design way enabled to estimate possibilities of applying the Autodesk Inventor program as a tool used for both creation and verification of virtual sugar beet lifter prototype.
Keywords*: sugar beet lifter, dynamic simulation, motion characteristics*

ANALIZA DYNAMICZNA WYORYWACZA BURAKÓW CUKROWYCH

Streszczenie

W pracy przedstawiono sposób tworzenia modelu 3D, etapy przygotowania oraz wyniki symulacji dynamicznej wyorywacza kombajnu do buraków cukrowych. W komputerowej symulacji uwzględniono wymuszenie kinematyczne i zadane wartości sił działających na lemiesz wyorywacza. Przedstawiony sposób projektowania pozwolił na ocenę możliwości zastosowania programu Autodesk Inventor jako narzędzia służącego zarówno do tworzenia jak i weryfikacji wirtualnego prototypu wyorywacza buraków cukrowych.
Słowa kluczowe: *wyorywacz buraków cukrowych, symulacja dynamiczna, charakterystyki ruchu*

Symbols

W – mechanism mobility,
n – number of mobile elements,
i – class of kinematic pair,
p_i – number of class *i* kinematic pair,
W' – real mechanism mobility,
r – number of passive constrains,
t – time, [s],
F_x – horizontal component of the force acting on the shares, [N],
F_y – vertical component of the force acting on the shares, [N],
ΔF_3 – force increment in the shock absorber spring, [N],
$\Delta\lambda_3$ – deflection of shock absorber spring, [mm],
Θ_1 – angular displacement in the revolute pair, [rad],
$\dot{\Theta}_1$ – angular velocity in the revolute pair, [rad/s],
F_{1x} – horizontal force the revolute pair, [N],
F_{1y} – vertical force the revolute pair, [N],
λ_3 – displacement in the prismatic pair, [mm],
$\dot{\lambda}_3$ – linear velocity in the prismatic pair, [m/s],
k – rigidity of the shock absorber spring, [N/mm],
c – dumping coefficient of shock absorber, [Ns/mm],
v – working velocity, [m/s].

1. Introduction

Demands of modern machine industry as well as development of designing and production systems make designers of designing and producers use the latest methods and tools of computer assigned designing. Contemporary designing is not confined only to elaboration of technical specifications with computation and designs but it includes also 3D modelling with the possibility of constructing and analysis of virtual prototypes. It shortens the time of production initiation and allows to avoid costs connected with construction and examination of real objects, enables analysis of many construction variants and can be used for the whole construction or single sub-assembly or element [5, 6, 8].

Individual stages of virtual prototyping that is model creation dynamic simulation as well as analysis of stresses and strains of construction elements can be conducted using individual systems of designing assistance [3]. An alternative way is the use of CAD system equipped with the additional module for verification and visualization of created 3D models [6]. Such possibilities are provided by the *Autodesk Inventor Professional* program exploited during preparation of this paper.

Application of designing assisted systems in investigations was the object of interest of many researches. In the paper [3] the authors presented the process of designing a storage injector of the engine feed system of self ignition. There was prepared a 3D model as well as the dynamic simulation of action and the strength analysis of one of the injector elements i.e. the atomizer, holder were conducted. *MSC Adams*, *Patran/MSC Nastran* and *Autodesk Inventor* were used in the paper. The paper [11] presents the course of the process consisting in elaboration and testing of supporting structure of one-man cross-country vehicle of electric drive. A vehicle model with the surrounding was created and subjected to dynamic simulation for five configurations of the vehicle-surrounding system. Resistance and rigidity of the designed frame were examined under the most disadvantageous load conditions. Based on the analysis results modification of the preliminary accepted supporting structure was made. This task was accomplished using the *Autodesk Inventor* were discussed in the successive stages of implementation of the model created in the dynamic simulation way. The authors proved that the results obtained from the studied on collector mathematical model are consistent with the effects of dynamic modelling in the *Autodesk Inventor* program and can be applied for evaluation of current collectors dynamic properties particularly in the designing stage. The process of designing and virtual testing of the prototype of suspension system of two types of three-wheel vehicles using the *Autodesk Inventor Professional* software is presented in the paper [6]. The created 3D models were analyzed in order to determine forces in individual suspension systems during going along the curved section of the road. The author proved that this method enables a very effective process of new product creation shortening the time needed for its entry into the production phase and effective evaluation of various construction variants. In [7] the problem connected with the dynamic simulation of driving gear of the car window is discussed. The way of elements combination, defining parameters of driving motion and outer loads as well as the courses of reaction forces in the chosen construction modes are presented. The results of dynamic simulation were used for the analysis of stresses and strains of mechanism elements applying the finished elements method. The analysis was based on the *Autodesk Inventor Professional* software.

The aim of the paper was designing the mechanical system of passive sugar beets lifter and carrying out preliminary tests using the dynamic simulation module in the Autodesk Inventor program. The aim of the presented way of designing and testing is also to evaluate the program as a tool for creation.

2. 3D model of sugar beets lifter

Figure 1 presents the 3D model of passive sugar beets lifter.

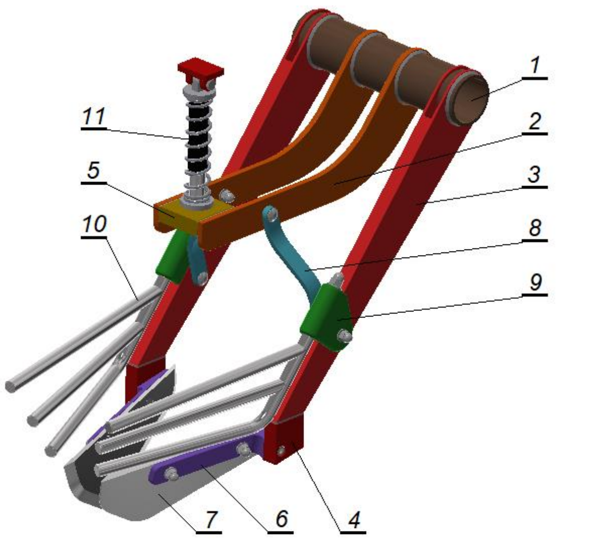

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Fig. 1. 3D model of sugar beets lifter (description in the text)
Rys. 1. Model 3D wyorywacza buraków cukrowych (opis w tekście)

The lifter body is made of welded load capacity construction composed of rotary sleeve 1, pendulum frame 2, lifter columns 3, lifter columns tips 4 and plate 5. Moreover, the lifter is equipped with shaping pads 6, shares 7, angle struts 8, holders of operating bars 9, operating bars 10, flexible system 11 in the spring form, shock absorber and fixing elements.

3. Description of the module - *Dynamic Simulation*

The *Dynamic Simulation* module of the *Autodesk Inventor* program is integrated with the *Standard.iam* module for the creation of parts assemblies. Owing to this it is possible not only to use the dynamic simulation module. The dynamic simulation refers to the behavior of the designed mechanism affected by the kinematic or strength-testing coercion. It enables determination of courses of kinematic (displacement, velocity, acceleration) and dynamic (strengths and moments) quantities in individual kinematic pairs taking into account mass, gravitation, friction and other quantities. The simulation was conducted in three stages:

- preparation of the 3D model for analysis which consists in separation of mechanism elements into stable and mobile links, formation of welded groups (connection of the elements which move together) and formation of connections between individual members of the mechanism being analyzed,
- defining the conditions simulating a real environment of mechanism work on which the information about the position of the initial system, friction, damping as well as kinematic or strength testing coercion is given,
- evaluation of the results made after the simulation consists in generation and analysis of courses of kinematic and dynamic quantities.

The key stage of dynamic simulation is creation of connections between the links of the mechanism [1, 9]. In the *Autodesk Inventor* program the connections are divided into standard, rolling, displaced, 2D contact and force. The standard connections correspond to the kinematic pairs classification. They can be formed manually or using the automatic conversion of assemblies connection. The other kinds of connections are formed only manually. In the dynamic simulation module all mechanisms are treated as spatial. Their mobility is calculated from the relation

$$W = 6 \cdot n - \sum_{i=1}^{5} i \cdot p_i \qquad (1)$$

where: W – mechanism mobility,
n – number of mobile elements,
i – class of kinematic pair,
p_i – number of class i kinematic pair.

In the case the real mobility of the mechanism W' is know after the structural analysis it is possible to calculate the number of passive constrains

$$r = W' - W \qquad (2)$$

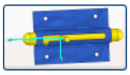
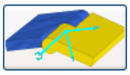
where:
r – number of passive constrains,
W' – real mechanism mobility.

The number of passive constraints r in the dynamic simulation module is called the degree of reduction but the real mobility W' is called the motion degree. The program examines without delay the connections state and informs the user about the redundant connections.

The 3D model of the lifter had the following joints: the base with the shock absorber cylinder - cylindrical, cylinder with the shock absorber piston - prismatic, shock absorber piston with the digger body - spherical and digger body with the base - revolute ones. Table 1 includes the joints of dynamic simulation module and their counterparts in the kinematic pairs classification.

In the case of the lifter model n=3, p_3=1 p_4=1, p_5=2. The mechanism mobility calculated from formula (1) is 1, the number of passive constraints calculated from formula (2) is 0.

Table 1. *Joints of the lifter elements used in the Dynamic Simulation module*
Tab. 1. Połączenia elementów wyorywacza wykorzystane w module Symulacja Dynamiczna

Name of joints	Symbol of joints	Description	Counterpart in the pair classification
Spherical		Rotations around the axes *x*, *y* and *z*.	Class III
Cylindrical		Rotations around the axis *z*. Displacement along axis *z*.	Class IV
Revolute		Rotation around the axis *z*.	Class V
Prismatic		Displacement along the axis *z*.	Class V

Source: own study / Źródło: opracowanie własne

5. Results of field tests and their implementation in the *Dynamic Simulation* module

The parameters of the mathematical model or those required for the computer simulation are very often obtained from the experimental studies and optimized with mathematical procedures [10]. Theoretical considerations and field studies concerning the application of sugar beet lifters construction are presented in paper [2]. As for the designed lifter the outer load was defined using the results of field tests described in the paper [4].

Fig. 2 presents the distribution of forces acting on the lifter share. Figs 3 and 4 show the field stands for the measurements of horizontal and vertical components.

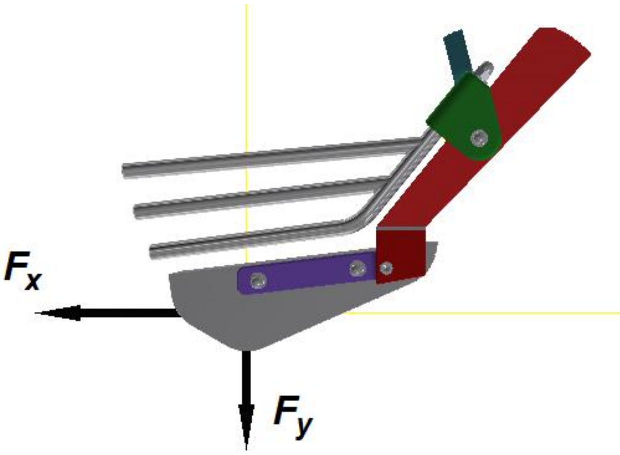


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Fig. 2. Components forces acting on the lifter share: F_x - horizontal component, F_y - vertical component
Rys. 2. Siły składowe działające na lemiesz wyorywacza F_x – składowa pozioma, F_y – składowa pionowa

Fig. 3. Stand for measuring the horizontal component of the force acting on the lifter share [4]
Fig. 3. Stanowisko do pomiaru składowej poziomej siły działającej na lemiesz wyorywacza [4]

Fig. 4. Stand for measuring the vertical component of the force acting on the lifter share [4]
Rys. 4. Stanowisko do pomiaru składowej pionowej siły działającej na lemiesz wyorywacza [4]

From the experimental courses there were formed the textual files including the values of component forces in the time functions which create a continuous function in the spline form when they are entered into the program. Fig. 5 and 6 present the splines of force horizontal F_x and vertical F_y courses created for simulation of three sugar beets lifting.

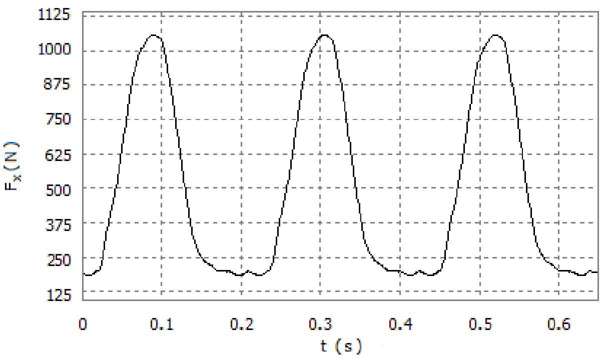

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Fig. 5. Spline of the course of horizontal force component acting on the lifter share
Rys. 5. Splajn przebiegu składowej poziomej siły działającej na lemiesz wyorywacza

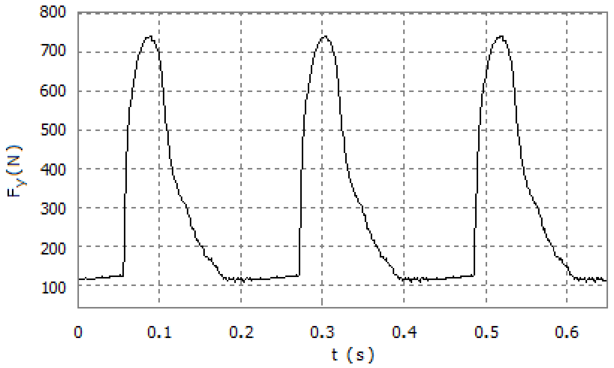

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Fig. 6. Spline of the course of vertical force component acting on the lifter share
Rys. 6. Splajn przebiegu składowej poziomej siły działającej na lemiesz wyorywacza

In the window *Force*, after indicating the point of force appllication and direction, one should choose *Input grapher* and then enter the textual files with the values of force components in the time function.

In the next stage rigidity of the shock absorber spring was determined. The course of the force acting on the shock absorber spring was found using the tool *Unknown force*. This tool determines of force or a turning moment necessary for keeping the mechanism in a defined position during the motion. Based on the obtained courses the increment of the force acting on the shock absorber spring $\Delta F_3 = 613.2$ N and that of spring deflection $\Delta\lambda_3 = 14.6$ mm for a given displacement of the lifter shares were evaluated. The spring rigidity was found from the relation

$$k = \frac{\Delta F_3}{\Delta\lambda_3} \tag{3}$$

where:

k – rigidity of the shock absorber spring, [N/mm],
ΔF_3 – force increment in the shock absorber spring, [N],
$\Delta\lambda_3$ – deflection of shock absorber spring, [mm].

The calculated spring rigidity k=42 N/mm.

Then there was put in the additional connection *Spring/Dumper/Jack* and the calculated spring parameters were introduced into the dialogue window. The results are obtained after setting simulation working using the tool *Output grapher*.

5. Results of simulation of sugar beet lifter motion

Simulation was conducted for the following data: the working velocity v=0.116 m/s, the distance between the beets l=0.25 m, the dumping coefficient of shock absorber c=0.5 Ns/mm, the time of simulation t=0.65 s.

Fig. 7 present the path of lifter share. The simulation result are presented in the form of chosen time courses of kinematic and dynamic quantities (Figs 8-13).

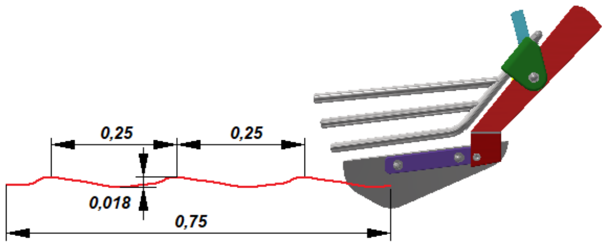

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Fig. 7. Path of the lifter share
Rys. 7. Tor ruchu lemiesza wyorywacza

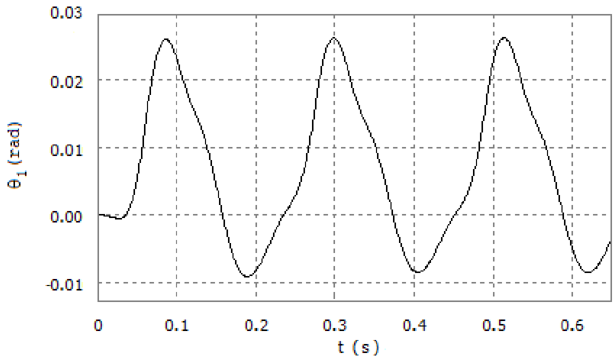

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Fig. 8. Course of the angular displacement of the lifter arm
Rys. 8. Przebieg przemieszczenia kątowego ramienia wyorywacza

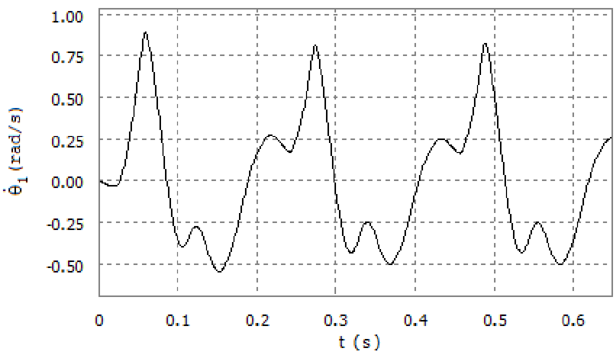

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Fig. 9. Course of the angular velocity of the lifter arm
Rys. 9. Przebieg prędkości kątowej ramienia wyorywacza

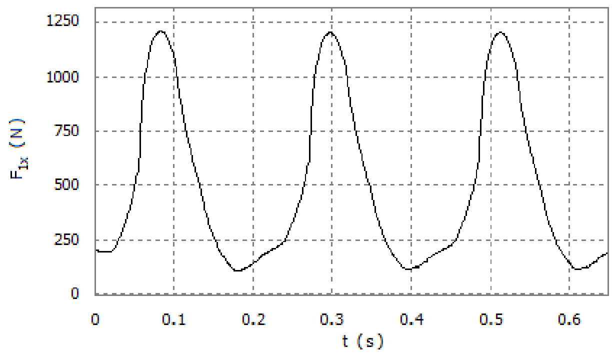

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Fig. 10. Course of the horizontal force in the revolute pair of the lifter
Rys. 10. Przebieg siły poziomej w parze obrotowej wyorywacza

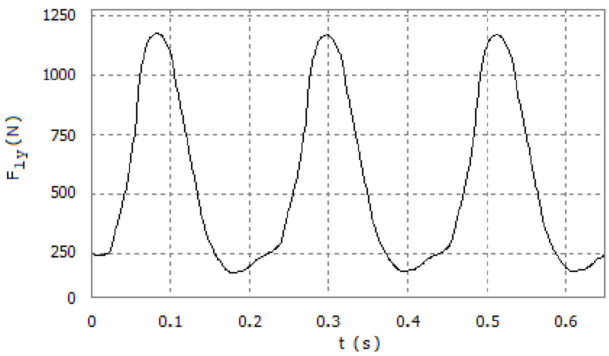

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Fig. 11. Course of the vertical force in the revolute pair of the lifter

Rys. 11. Przebieg siły pionowej w parze obrotowej wyorywacza

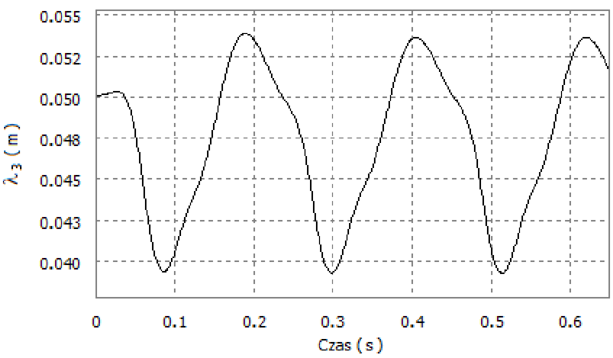

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Fig. 12. Course of the displacement in the prismatic pair of the lifter

Rys. 12. Przebieg przemieszczenia w parze pryzmatycznej wyorywacza

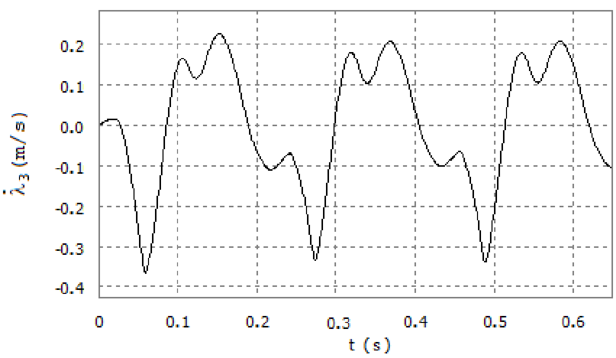

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Fig. 13. Course of the linear velocity in the prismatic pair of the lifter

Rys. 13. Przebieg prędkości liniowej w parze pryzmatycznej wyorywacza

The angular displacement in the revolute pair of the lifter θ_1 (Fig. 8) is in the range -0.009 – 0.026 rad (-0.53° – 1.51°) but the angular velocity $\dot{\theta}_1$ (Fig. 9) changes in the range -0.55 – 0.89 rad/s (-31.3°/s – 51.1°/s). The character of angular velocity changes during both the increase and decrease is significantly different from the linear one. In the angular velocity courses there appear the so called "saddles" (Fig. 9) which may result in the excessive exploitation wear if the connection elements. The courses of horizontal F_{1x} (Fig. 10) and vertical F_{1y} (Fig. 11) forces in the revolute pair correspond to that of the horizontal force F_x acting on the lifter share. The value of the horizontal force F_{1x} is in the range 107.3 – 1211.4 N but that of the vertical one F_{1y} 168.9 – 1117.8 N. The displacement course in the lifter prismatic pair λ_3 (Fig. 12) simultaneously being the change of spring and shock absorber length reminds the reversed course of angular displacement of the lifter arm θ_1. Its range is from 39.3 mm to 53.9 mm. The linear velocity changes in the range -0.36 – 0.22 m/s and its course (Fig. 13) reminds the reversed course of the angular velocity in the lifter revolute pair.

Dynamic equations are integrated a five order Runge-Kutta integration scheme. Integration error is compared to the user-defined parameter "solver precision" which is equal to 10^{-6}. If the integration error does not exceed the solver precision, the step is accepted, otherwise the integration step is automatically reduced.

6. Summary

Conclusions, as follows from the paper:

- in the modelling and simulation processes the choice of values of the parameters directly affecting the analysis results is of significant importance. Therefore exploiting the results of real investigations in the simulation studies affects directly precision of calculations,
- analysis of the virtual prototype using the data obtained from the experimental studies implemented in the form of splines enables determining the time courses of other kinematic and dynamic quantities whose actual measurements would be technically difficult or impossible for accomplishment due to some limitations e.g. of equipment, assembly, finances etc.,
- creation of 3D model and its examination using the module dynamic simulation in one environment enables a quick analysis of the designed construction as well as easy changes and modification,
- determination of the ranges of forces and moment in the lifter mobile connections, particularly their extreme values for the assumed courses of exterior forces which can be applied for estimation of the effort of some construction elements.

The perspective plans are the studies on application of the systems enabling infinitely variable adjustment and control of spring rigidity which can affect indirectly action of the lifting mechanism presented in the paper. Application of such systems will be an alternative construction solution to the currently used active lifters.

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