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# WOOD WASTE PROCESSING AS AN ALTERNATIVE FUEL ECONOMY

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*Being dependent on energy carriers, Ukraine becomes dependent on energy carrier exporters, who constantly increase their cost, which worsens the already economic and social situation in the country. Therefore, the demand for alternative types of fuel is aimed at saving money, as well as improving the ecological situation in the state.*

*The main direction of the introduction of alternative renewable resources in Ukraine is the introduction of biomass. Its use, which is based on the consumption of organic substances of plant origin, such as wood, straw, livestock waste, is the most promising.*

*Today, biomass ranks fourth as a fuel in the world and accounts for about 15% of total consumption, and in the countries of Finland, Sweden, and Denmark it accounts for more than 20%. One of the available sources is the use of wood waste, which is obtained in the process of logging, as well as when clearing bushes in forest strips. About 3.0 million m³ of logging residues are burned annually, which can effectively replace about half a billion cubic meters of natural gas due to their calorific value. Before the beginning of the crisis, when gas prices were relatively low, other sources were little used, but when the price of natural gas increased, the use of alternative sources became very relevant.*

*The use of biological mass to obtain alternative sources of energy is the most promising method of developing alternative types of energy in Ukraine. Bioenergy is based on the use of organic sources of plant origin and can save about 10% of energy needs.*

*The market of Ukraine presents a large amount of equipment, both domestic and foreign, for the processing of wood waste. However, the choice of this technological complex of equipment depends on the features of the customer's needs and his financial capabilities.*

***Key words:*** *alternative energy sources, garden mulching, wood waste shredder.*

***F. 28. Fig. 5. Ref. 14***

## 1. Problem formulation

Considering the biomass of wood waste as the main source for obtaining an alternative type of fuel, it is necessary to determine the sources of obtaining this type of raw material. Wood waste is obtained as a result of the work of various enterprises of the national economy: forestry farms, communal enterprises, road services, enterprises of the processing industry. As a result of their activity, a large amount of wood waste such as: sawdust, wood chips, and tree branches up to 15 cm thick is generated annually. Most of this waste is not processed, but remains as a by-product and is not used in further production. Sawdust is mainly used, and other types of wood waste are usually not used or processed, but are burned or rotted in the places where they are harvested. During the clearing of forest strips, a large amount of wood waste is formed, this waste in the long term is the main idle resource that can provide cheap environmentally friendly fuel. However, the process of clearing forest strips is quite time-consuming and requires a significant amount of manual labor. At the moment, there are no means of mechanizing the process of clearing forest strips due to a number of technical problems. Existing means of mechanization are intended for manual use only. These include: chainsaws, brush cutters, and branch cutters. [1].

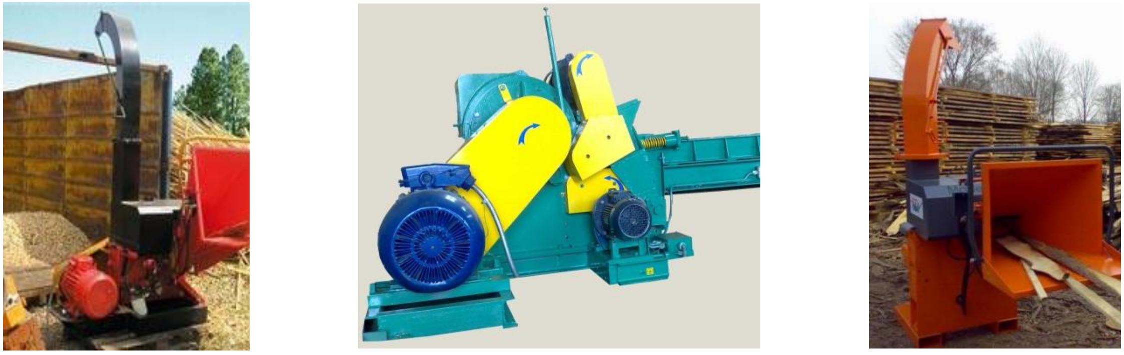
## 2. Analysis of recent research and publications

These means of mechanization allow high-quality cleaning of forest strips in hard-to-reach places: between trees, on slopes and hills. Chainsaws allow you to cut trees of great thickness and in various hard-to-reach places with high productivity, but they have a negative impact on a person during work. Chainsaws have restrictions on the thickness of cut trees up to 12 cm in diameter, but they have less impact on a person during work.

Therefore, at the moment, cleaning of forest strips is possible only with the use of manual means of mechanization of the process.

The use of wood waste obtained in the process of clearing forest strips is possible only when they are processed. Wood waste can be processed into sawdust, chips, pellets, granules, briquettes. The process of processing wood waste can consist of two stages, primary and secondary processing. As a result of primary processing, we get chips, and after secondary processing (complete) granules, pellets, briquettes.

The primary processing of wood waste includes: accumulation of wood waste in certain places for further processing, initial grinding into chips, transportation to places of storage or use. The primary processing of wood waste into chips is carried out by the following machines (Fig. 1): RM-800, DP-660E, MRB-2AP and others. [2]. After primary processing, wood chips can be burned in solid fuel boilers of the series: UAS, P6-KOVA, etc..



***a – DP-660E*** ***b – МРБ-2АП*** ***c – RM-800***

***Fig. 1. Logging machines: a – DP-660E of the Olnova company; b – MRB-2AP of UKRPKTIlisprom; c – RM-800 of the firm "HEMMEL-Ukraine" LLC.***

However, direct burning of wood chips is low-efficiency, due to its low calorific value, and low efficiency of wood-burning boilers. The formation of pyrolysis gas in boilers is also a significant drawback. Improper loading, or loading wood chips with a moisture content of more than 70%, may cause an explosion. To exclude these negative phenomena, further processing of the wood chips is carried out. [3]

Secondary processing of wood waste includes the processing of wood chips into sawdust, drying of sawdust, and processing of sawdust into briquettes, pellets or pellets. Secondary processing is necessary to facilitate the process of automating the burning of wood waste in boilers, reducing the required area for storage of wood waste processing products, and facilitating transportation. Secondary chip shredders are used to process wood chips into sawdust. The shredder is installed both indoors and in a pair of shredding complexes on an open site, under cover.

In the complex between the primary and secondary shredders, a hopper-doser is used for uniform supply of wood chips after primary grinding. The resulting sawdust is used for the production of chipboard, fiberboard, briquettes, pellets, as well as for burning in heating boilers.

Processing of sawdust into pellets, granules, briquettes is carried out using a complex of machines. Mandatory elements of this complex of machines are: primary and secondary shredders, drying, transport equipment (for transporting raw materials between technological operations of production of wood waste processing products), machines for the production of granules (granulators), pellets (press, extruders), briquettes (press).

As a result of the operation of this complex of machines, we receive cheap, environmentally friendly fuel: fuel briquettes, pellets and granules (Fig. 2). [4-6].

The market of Ukraine presents a large amount of equipment, both domestic and foreign, for the processing of wood waste. However, the choice of this technological complex of equipment depends on the features of the customer's needs and his financial capabilities.

*Fig. 2. Ecological fuel obtained from wood waste.*

The aim of the study. The successful work involved a study of the design parameters of the wood chipper DP660E, which was purchased in 2012 and is currently in operation. The characteristics of this machine are as follows: Type - mobile with a hydraulic drive of a knife disk and feed mechanisms. The diameter of the knife disk is 800 mm. Productivity t/h - 4t. Sizes of wood to be chopped: Diameter up to 60 mm. Width up to 240 mm. Length from 200 to 2000 mm. Drive power up to 50 kW.

## 3. Results of the researches

The disadvantage of most mobile units is their low productivity and the inability to productively process bushes with a trunk thickness of more than 10 cm into wood chips. This problem is solved when using stationary machines, they are able to process branches up to 15 cm thick and higher into wood chips with a productivity of up to 4 tons per hour. Since the thickness of the trunk of most of the branches obtained as a result of cleaning works does not exceed 15 cm, these machines are the best suited for use in our conditions. Stationary machine power 30 kW, productivity up to 20 m3/h, chip size from 8 to 40 mm depending on the number of knives.

This work proposes the development of a mobile unit based on the DP 660 E primary wood waste shredder by replacing the stationary 30 kW engine with a hydraulic drive.

The drive of the felling machine is made using the MP-90 hydraulic motor. The modernized hydrostatic transmission consists of: an adjustable NP-90 pump and two MP-90 hydraulic motors. It is known that hydrostatic transmission is used on many self-propelled machines such as grain harvesters, fodder harvesters, beet harvesters. The modernized machine works as follows. When moving to the logging site, the machine uses the pump NP-90 3. and the hydraulic motor MP-90 16. When the machine arrived at the work site, distributor 19 is moved to position B, and distributor 7 to position B1, which activates the hydraulic motor MP –90 10, and turns off the MP-90 16 hydraulic motor. The brush is fed manually by the worker. At the end of the work of the felling machine, the distributor 19 is moved to position A, and the distributor 7 to position A1, this leads to turning off the hydraulic motor 10 and turning on the hydraulic motor 16 for the movement of the machine (Fig. 3). [7-9].

This modernization made it possible to increase the effective power of the felling machine due to the use of a hydraulic drive. It is possible to install the shredder on self-propelled units with hydrostatic wheel drive, for example, grain harvesters and beet harvesters. In this case, the installation was mounted on a KS-6B forage harvester in 2012. [13].

Mathematical modeling

To study the dynamics of the hydraulic drive of the shredder, mathematical modeling of its operation was performed.

We are modeling only the drive system of the active working body, the section with the drive wheels was not taken into account.

When developing a mathematical model of the hydraulic drive of the shredder, the following simplifications were adopted:

– the compressibility coefficient of the working fluid changes insignificantly with the change in pressure and is therefore considered constant;

– fluid flow rates from a high-pressure area to a low-pressure area are directly proportional to the pressure drop at the boundaries of these areas and are characterized by the working fluid flow coefficient σ;

– the value of the pressure drop between the filter and the hydraulic pump is insignificant, therefore it is not taken into account [10-12];

– the thermal regime of the system is considered stable;

– viscous friction losses in the hydraulic motor are proportional to the speed of rotation;

– wave processes in pipelines are not considered due to the short length;

– pressure losses in the distributor are small, so they were also not taken into account in the calculations.

A simplified calculation scheme of the hydraulic drive of the shredder is shown in the figure. 3.

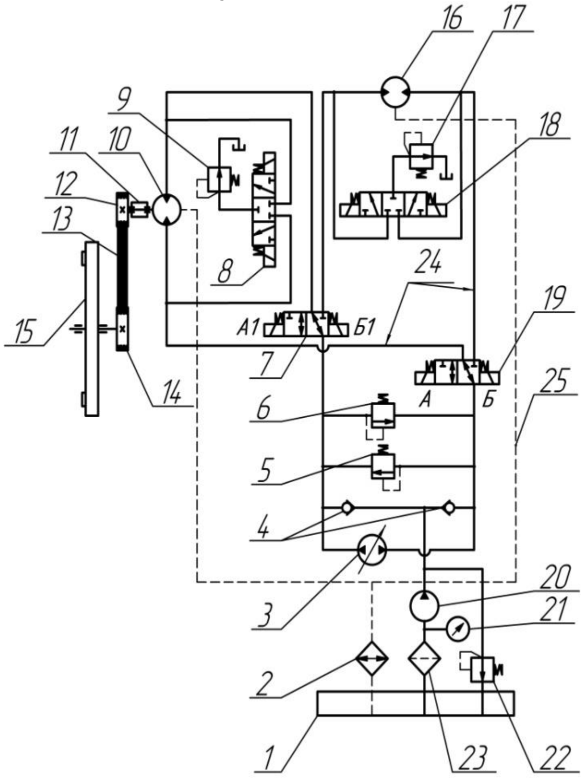



***Fig. 3 - Scheme of the hydrostatic transmission of the root harvesting machine KS-6B:***
***1 – closed hydraulic tank; 2 – radiator; 3 – adjustable hydraulic pump; 4 – safety valves; 5, 6 – bypass valves; 7, 8, 18, 19 – hydraulic distributor; 9, 17, 22 – drain valves; 10 – hydraulic motor of the cutting disc drive; 11 – bearings; 12 – leading pulley; 13 – belt transmission; 14 – driven pulley; 15 – cutting disk; 16 – drive wheel drive hydraulic motor; 20 – hydraulic pumping pump; 21 – manometer; 23 – filter; 24 – hydraulic pipes; 25 – drainage hydraulic pipe.***

This system consists of a reservoir (tank) for working fluid - B; filter - F; refrigerator - X; adjustable hydraulic pump - RGN; non-return valves - ZK1, ZK2; bypass valves PC1, PC2, PC3, PC4; hydraulic distributors - GR1, GR2, GR3; drain valve - ZlK1; pressure gauge - M, hydraulic motor - ГМ, which drives the drive pulley of the belt transmission - PP, cutting disc - RD, leading pulley - ВШ, driven pulley - ВдШ; pumping pump - NP.

The torque from the drive pulley is transmitted through the PP belt transmission to the driven pulley, which in turn transmits the torque to the working bodies, thus driving the cutting disc of the RD.

In fig. 4 shows the calculation diagram of the hydraulic drive of the grinding mechanism. [4]

When compiling the mathematical model, the following simplifications were adopted:

- paging mechanism 1 is turned on before starting the main system;
- the mechanism works in stationary mode, hydraulic distributors 2 and 3 remain in positions B and B1;
- the safety mechanism 4, combined with the drive hydraulic motor, is included in its design.

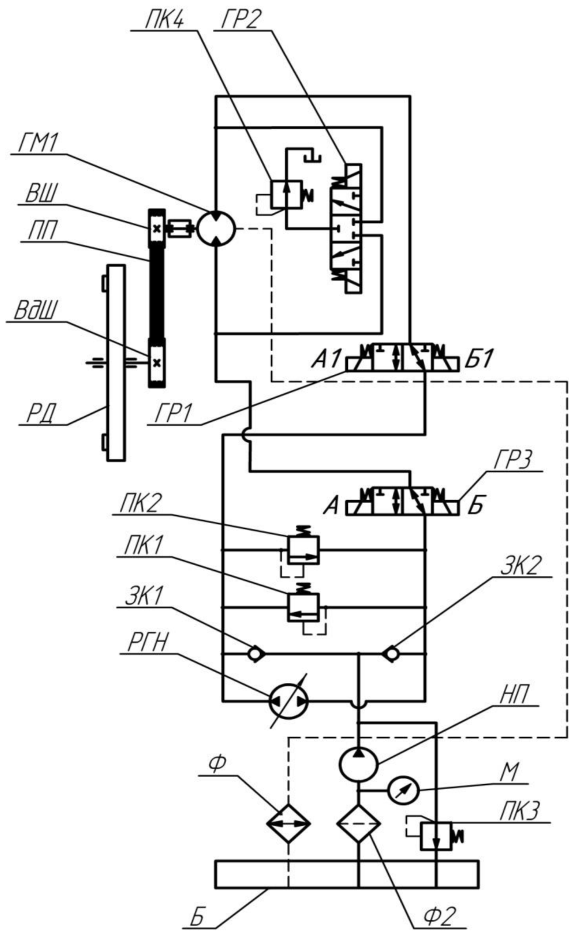



*Fig. 4. Structural and functional scheme of the mechanism.*

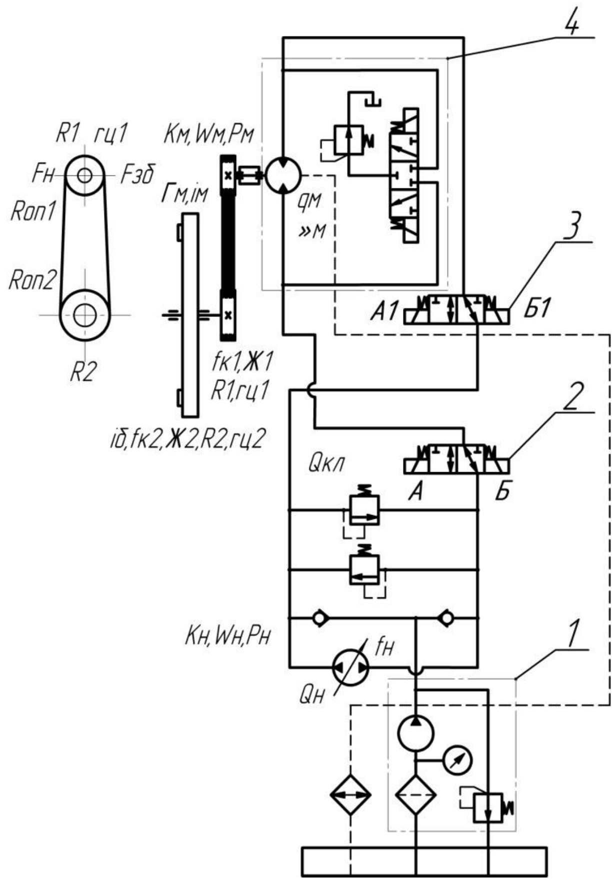



*Fig. 5. Calculation scheme of the grinding mechanism.*

After building the calculation scheme, we apply all the forces and elements to it, where:

$Q_{н.}$ – pump costs;

$Q_{кл.}$ – flow of liquid through the valve;

$K_{н.}$ – the coefficient that characterizes the losses in the pressure line;

$W_{н.}$ – the volume of the pressure main;

$P_{н.}$ і $P_{м.}$ – pressure in the pressure and supply mains;

$f_{н.}$ – pump area;

$Q_{м.}$ – flow rate of liquid that passes through the working chambers of the hydraulic motor;

$K_{м.}$ – coefficient that characterizes the losses in the fluid supply line to the hydraulic motor;

$W_{м.}$ – the volume of the fluid supply line to the hydraulic motor;

$P_{м.}$ – pressure in the main line at the entrance to the hydraulic motor;

$q_{н.}$ і $q_{м}$ – working volume of the pump and hydraulic motor;

$\lambda_{м}$ – coefficient of mechanical losses in the hydraulic motor;

$\sigma_{м.}$ і $\sigma_{н.}$ – flow coefficient between the cavities of the hydraulic motor and the pump;

$I_{м.}$ – the moment of inertia, which takes into account the inertial properties of the hydraulic motor shaft, the drive pulley, and the rest of the parts that rotate in this node;

$f_{к.1}$ і $f_{к.2}$ – coefficients of rolling friction;

$\varphi_1$ і $\varphi_2$ – angular speed of rotation of the driving and driven shafts;

$R_1$ і $R_2$ – radii of the drive and driven pulleys;

$r_{ц.1}$ і $r_{ц.2}$ – the radius of the trunnion (shaft) of the drive and driven;

$R_{оп.1}$ і $R_{оп.2}$ – reactions in the supports of the drive and driven shafts;

$F_{н.}$ і $F_{зб.}$ – approaching and converging forces on the pulleys.

First, let's make the equation of the balance of costs in the pressure main: [14].

$$Q_{н.} = Q_{др.} + Q_{кл.} + Q_{вт.н.} + Q_{ст.н}. \quad (1)$$

де $Q_{др.}$ – fluid flow through the throttle; $Q_{вт.н.}$ – fluid losses in the pressure line; $Q_{ст.н.}$ – liquid compression in the pressure line.

$$Q_{н.} = n_{н.} \cdot q_{н.} - \sigma_{н.} \cdot P_{н}, \quad (2)$$

where $n_{н.}$ – pump rotation frequency.

$$Q_{др.} = f_{н.} \cdot \mu \cdot \sqrt{\frac{2}{\rho}} \sqrt{P_{н.} - P_{м.}}, \quad (3)$$

де $\mu$ – cost factor; $\rho$ – liquid density.

$$Q_{кл.} = Q_{н.} - Q_{мдр}, \quad (4)$$

$$Q_{вт.н.} = K_{н.} \cdot P_{н}, \quad (5)$$

$$Q_{ст.н.} = \frac{W_{н.}}{E} \frac{dP_{н.}}{dt}, \quad (6)$$

where $E$ –modulus of elasticity of the working fluid.

Therefore, equation (1) will have the form:

$$n_{н.} \cdot q_{н.} - \sigma_{н.} \cdot P_{н.} = f_{н.} \cdot \mu \cdot \sqrt{\frac{2}{\rho}} \sqrt{P_{н.} - P_{м.}} + Q_{кл.} + \; + K_{н.} \cdot P_{н.} + \frac{W_{н.}}{E} \frac{dP_{н.}}{dt}. \quad (7)$$

Let us present equation (7) in the Cauchy form:

$$\frac{W_{н.}}{E} \frac{dP_{н.}}{dt} = f_{н.} \cdot \mu \cdot \sqrt{\frac{2}{\rho}} \sqrt{P_{н.} - P_{м.}} - Q_{кл.} - K_{н.} \cdot P_{н.} - n_{н.} \cdot q_{н.} + \sigma_{н.} \cdot P_{н}. \quad (8)$$

Let's make an equation for the balance of costs in the supply line to the motor:

$$Q_{др.} = Q_{м.} + Q_{вт.м.} + Q_{ст.м}. \quad (9)$$

where $Q_{вт.м.}$ –fluid loss in the supply line to the hydraulic motor; $Q_{ст.м.}$ – compression of the fluid in the supply line to the hydraulic motor,

$$Q_{м.} = n_{м.} \cdot q_{м.} - \sigma_{м.} \cdot P_{м}. \quad (10)$$

where $n_{м.}$ – frequency of rotation of the hydraulic motor shaft,

$$Q_{вт.м.} = K_{м.} \cdot P_{м}, \quad (11)$$

$$Q_{ст.м.} = \frac{W_{м.}}{E} \frac{dP_{м.}}{dt}. \quad (12)$$

Therefore, equation (14) takes the form:

$$f_{н.} \cdot \mu \cdot \sqrt{\frac{2}{\rho}} \sqrt{P_{н.} - P_{м.}} = n_{м.} \cdot q_{м.} - \sigma_{м.} \cdot P_{м.}. + K_{м.} \cdot P_{м.} + + \frac{W_{м.}}{E} \frac{dP_{м.}}{dt}. \quad (13)$$

Let's express the obtained equation (13) in the Cauchy form:

$$\frac{W_{м.}}{E} \frac{dP_{м.}}{dt} = n_{м.} \cdot q_{м.} + \sigma_{м.} \cdot P_{м.} - K_{м.} \cdot P_{м.} + f_{н} \cdot \mu \cdot \sqrt{\frac{2}{\rho}} \sqrt{P_{н.} - P_{м.}}. \quad (14)$$

The equation of motion of the drive pulley shaft has the form:

$$M_{мот.} = M_{прив.шк.} + M_{т.прив.шк.} + M_{ін.прив.шк}. \quad (15)$$

where $M_{мот.}$ – moment, which is created on the shaft of the hydraulic motor; $M_{прив.шк.}$ – the moment that is created on the drive pulley; $M_{т.прив.шк.}$ – friction losses in the bearings of the drive pulley; $M_{ін.прив.шк.}$ – moment of inertia of the drive pulley.

$$M_{мот.} = q_{м} \cdot (P_{м.} - P_{зл.}) - \lambda_{м} \cdot (P_{м.} - P_{зл.}). \quad (16)$$

where $P_{зл.}$ – pressure in the drain line,

$$M_{прив.шк.} = (F_{н.} - F_{зб.}) R_1, \quad (17)$$

$$M_{т.прив.шк.} = f_{к.1} \cdot R_{оп.1} \cdot r_{ц.1} \cdot sign \frac{d\varphi_1}{dt}. \quad (18)$$

where $sign$ –ign – a linear function that changes the sign from +1 to -1 depending on the sign of the derivative, which allows you to set the direction of the friction force depending on the direction of rotation of the shaft.

$$M_{ін.прив.шк.} = I_{м.} \frac{d^2\varphi_1}{dt^2}. \quad (19)$$

Therefore, equation (10) will have the form:

$$q_{м} \cdot (P_{м.} - P_{зл.}) - \lambda_{м} \cdot (P_{м.} - P_{зл.}) = (F_{н.} - -F_{зб.}) R_1 + + f_{к.1} \cdot R_{оп.1} \cdot r_{ц.1} \cdot sign \frac{d\varphi_1}{dt} + I_{м.} \frac{d^2\varphi_1}{dt^2}. \quad (20)$$

Or,

$$I_{м.} \frac{d^2\varphi_1}{dt^2} + f_{к.1} \cdot R_{оп.1} \cdot r_{ц.1} \cdot sign \frac{d\varphi_1}{dt} = (F_{н.} - F_{зб.}) R_1 + q_{м} \cdot (P_{м.} - P_{зл.}) + \lambda_{м} \cdot (P_{м.} - P_{зл.}). \quad (21)$$

Let's write the equation of motion of the shaft of the driven pulley:

$$M_{вед.шк.} = M_{тех.нав.вед.шк.} + M_{т.вед.шк.} + M_{ін.вед.шк}. \quad (22)$$

where $M_{\text{вед.шк.}}$ – the moment that is created on the driven pulley; $M_{\text{тех.нав.вед.шк.}}$ – technological load moment, which is created on the driven pulley [6-8]; $M_{\text{ін.вед.шк.}}$ – moment of inertia force on the driven pulley.

$$M_{\text{вед.шк.}} = (F_{\text{н.}} - F_{\text{зб.}})R_2. \quad (23)$$

$$M_{\text{тех.нав.вед.шк.}} = 0.00025\frac{Q_{\text{и}}V_{\text{в}}S_{\text{м}}n_{\text{мр}}K_{\text{р}}L_{Д}}{\pi R_{\text{р}}h_{\text{ц}}L_{\text{к}}V_{\text{сл}}}\mathfrak{f}_{\text{тр}}. \quad (24)$$

where $Q_{\text{и}}$ – shredder performance; $V_{\text{в}}$– relative speed of knives, m/s; $S_{\text{м}}$– surface area of the loaded part of the knife in the material layer, m$^2$; $n_{\text{мр}}$ – the number of knives in one row; $L_{Д}$ – deck length, m; $h_{\text{ц}}$ – thickness of the circulating layer, m; $L_{\text{к}}$ – width of the grinding chamber, m; $V_{\text{сл}}$ – speed of the material layer in the shredder chamber, m/s; $\mathfrak{f}_{\text{тр}}$ – coefficient of friction of mass movement on a steel surface.

$$M_{\text{т.вед.шк.}} = f_{\text{к.2}} \cdot R_{\text{оп.2}} \cdot r_{\text{ц.2}} \cdot sign\frac{d\varphi_2}{dt}, \quad (25)$$

$$M_{\text{ін.вед.шк.}} = I_{\text{б.}}\frac{d^2\varphi_2}{dt^2}. \quad (26)$$

where $I_{\text{б.}}$ – the moment of inertia, which takes into account the inertial properties of the driven pulley, the shaft, the grinding disk, and the rest of the parts that rotate in this unit.

Therefore, this equation will have the form:

$$(F_{\text{н.}} - F_{\text{зб.}})R_2 = 0.00025\frac{Q_{\text{и}}V_{\text{в}}S_{\text{м}}n_{\text{мр}}K_{\text{р}}L_{Д}}{\pi R_{\text{р}}h_{\text{ц}}L_{\text{к}}V_{\text{сл}}}\mathfrak{f}_{\text{тр}} + f_{\text{к.2}} \cdot R_{\text{оп.2}} \cdot r_{\text{ц.2}} \cdot sign\frac{d\varphi_2}{dt} + I_{\text{б.}}\frac{d^2\varphi_2}{dt^2}. \quad (27)$$

After transformations we get,

$$I_{\text{б.}}\frac{d^2\varphi_2}{dt^2} + f_{\text{к.2}} \cdot R_{\text{оп.2}} \cdot r_{\text{ц.2}} \cdot sign\frac{d\varphi_2}{dt} =$$

$0.00025\frac{Q_{\text{и}}V_{\text{в}}S_{\text{м}}n_{\text{мр}}K_{\text{р}}L_{Д}}{\pi R_{\text{р}}h_{\text{ц}}L_{\text{к}}V_{\text{сл}}}\mathfrak{f}_{\text{тр}}$ +.00025Q_иV_вS_мn_мрK_pL_Д/πR_p$h$_цL_кV_слʃ_тр+$(F_{\text{н.}} - F_{\text{зб.}})R_2$. (28)

The compiled equations correspond to the structural diagram presented above, they can be used in the future for mathematical modeling of the operation of the hydraulic drive and determining the rational values of its parameters.

## 4. Conclusions

The use of wood waste as a source of energy is the most promising in the development of bioenergy, both in terms of energy and ecology. According to forecasts, if all existing wood waste is processed and used as fuel, it is possible to obtain 2.8 billion kW of energy, which is equivalent to 500 million m$^3$ of natural gas, therefore the formation of the appropriate structure of the wood waste harvesting and processing process is quite relevant.

The second direction of using wood waste in an ecological way, in particular for mulching trees in parks and gardens, will create better conditions for the development of trees due to the preservation of moisture and reduce the use of chemicals. Mulching will make it possible to improve the quality of the soil due to organic matter from the rotting of wood residues.

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**ПЕРЕРОБКА ДЕРЕВИННИХ ВІДХОДІВ ЯК АЛЬТЕРНАТИВНА ЕКОНОМІЯ ПАЛИВА**

*Будучи залежною від енергоносіїв Україна потрапляє в залежність від експортерів енергоносіїв, які постійно підвищують їх вартість, що погіршує і так економічну і соціальну ситуацію в державі. Тому попит на альтернативні види палива направлені на заощадження коштів, а також покращення екологічної ситуації в державі.*

*Основним напрямом впровадження альтернативних відновлюваних ресурсів в Україні є впровадження біомаси. Її використання, яке базується на споживанні органічних речовин рослинного походження таких, як деревина, солома, відходи тваринництва, являється найбільш перспективним.*

*Сьогодні біомаса займає четверте місце, як паливо, у світі і становить близько 15% від загального споживання, а в країнах: Фінляндія, Швеція, Данія складає більше 20%. Одним із доступних джерел є використання відходів деревини, які отримують в процесі лісозаготівель, а також при очищені кущів в лісосмугах. Щорічно спалюють біля 3,0 млн. м³ лісосічних залишків, які ефективно завдяки теплотворної здатності, можуть замінити близько півмільярда кубометрів природного газу. До початку кризи, коли ціни на газ були відносно низькими, інші джерела мало використовувались, проте коли ціна на природній газ збільшилася, то використання альтернативних джерел, стало дуже актуальним.*

*Використання біологічної маси для отримання альтернативних джерел енергії є найперспективнішим методом розвитку альтернативних видів енергії в Україні. Біоенергетика грунтується на використанні органічних джерел рослинного походження і може заощадити близько 10% потреб в енергетиці.*

***Ключові слова:*** *альтернативні джерела енергії, мульчування садів, подрібнювач відходів деревини.*

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