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New Technologies, Techniques, Ecological Aspects of Cleaning-Up and Maintenance of Roads, Territories and Production Facilities

Victor Gennadievich Chertov, Alexandr Vladimirovich Belousov and Natalia Viacheslavovna Kornilova
Belgorod State Technological University (BSTU) Named after V.G. Shukhov, Kostyukova Street 46, 308012 Belgorod, Russia

Abstract: The present research describes portable pneumatic transportation plants allowing to achieve a triple environmental impact, to improve significantly economical and technical parameters of the plants, to reach a severalfold efficiency increase, to mechanize and ultimately to automate the process of construction, repair, dust handling at the enterprises, on the roads and territories. Researchers analyzed advantages of use of a Gas Turbine Unit (GTU) as a drive for portable pneumatic transportation plants which eliminates the need for multiple power conversion causing unnecessary losses since conversion of gas energy into electrical and then into mechanical energy is not required, therefore, there is no need in a generator, a frequency converter and a reduction gear the cost of which in aggregate may constitute >50% of a gas-turbine unit value. Realization of technical capabilities of modern home-produced PPTP will not be possible without new technical solutions, materials, equipment, automatic equipment, production and maintenance technologies, electronic equipment, qualified personnel, i.e., without achievements of the scientific and technological complex of our country.

Key words: Energy and resource saving, range of portable pneumatic transportation plants, motorized vacuum cleaning, GTU, equipment

INTRODUCTION

Collection of spillage and dust masses is a problem of great importance for the construction materials industry. Collection often involves many thousands of square meters of the production areas and the adjacent territories where the necessary cleaning up is normally performed in a manual mode and moreover in the harmful ecological environment since there is no any kind of dust useful for the human health. Collection of spillage and dust masses is especially important at time of elimination of consequences of and prevention of accidents, hazardous emissions and particularly for the low-staffed enterprises dealing with production of industrial construction materials. Therefore, dust cleaning is not only a means of elimination of technogenic failures consequences but also a way effective prevention of accidents and catastrophes probability of which increases with increase of equipment wear. Industrial dust cleaning eliminates the above problems thus ensuring compliance with the sanitary requirements and operation safety enhancement and is performed by the portable pneumatic transportation plants productivity improvement of which is being considered herein (Chertov, 2009a-c, 2006a, b).

MAIN PART

Russia made a significant contribution to development of gas turbines engineering; jets started to be widely used in German pilotless aircrafts and Russian missilery during the World War II. Until recently Russia played a key role in production of the gas turbine engines (mainly for defense purposes) among the principal world manufacturers (USA, England, France). At the present time, Russia is a world leader of the International Space Station maintenance and gas turbine rotor blades production.

Great success achieved in engineering of gas turbines designed for aviation and transportation industries and high potential of the home scientific and design organizations as well as of machine engineering, instrument-making and electronics engineering sectors which is indicative of the technical level of the country gave a powerful impulse for revision of the design concept for stationary and portable Gas Turbine Units (GTU) towards more wide application of innovative block design principles.

Use of the principle of a block-modular design or a block design is the best way to implement such advantages peculiar for GTU as compared to other types of engines like high specific power, good maneuvering capabilities, high reliability and automation levels,

Corresponding Author: Victor Gennadievich Chertov, Belgorod State Technological University (BSTU) Named after V.G. Shukhov, Kostyukova Street 46, 308012 Belgorod, Russia

comparatively low production cost, low repair and maintenance costs which is of fundamental importance for such spheres of application as air, water and land transport and portable GTU. It is the circumstance that explains steady development of the mentioned principle as an effective way for serial production preparation.

Low-power gas turbine units become more and more widely used throughout the world and are being developed by a range of American companies: Ford models 705, 707, 2500, 3600, 4200 with the power from 275-485 kW, General Motor models GT-305, T-309 with the power of 165, 205 kW, Detroit Diesel models 250, 400 with the power of 205, 295 kW, Chrysler Models 2A, A-831 with the power of 103, 95 kW, Solar models T-600, T-1000 with the power of 440, 880 kW, Avco Lycoming Model AGT-1500 with the power of 1100 kW, Williams Model 8 with the power of 59 kW, General Electric models T-53, T-58 with the power of 845, 770 kW; British companies: Rover models 2/140R, 2/150R, 2/350R with the power of 103, 107, 272 kW, Layland Model MK-2 with the power of 294 kW; German companies: Daimler Benz Model E300 with the power of 250 kW, MAN Model 350 with the power of 250 kW; Japan company: Nissan Model RT-12 with the power of 220 kW; French company: Turbomeca model with the power of 515 kW; Italian company: FIAT Model 6891-002 with the power of 368 kW; Swedish company: Volvo Model 250 with the power of 184 kW; Russian models TurboNAMI with the power of 260 kW, VK-1 with the power of 900 kW, GTE-0.6 and GTE-1.6 with the power of 600 and 1600 kW, AI-20 and AI 25 with the power of 400 and 300 kW, M-701 with the power of 310 kW, GTD-1T with the power of 735 kW, GTU with the power 270 kW, P311-V300 with the power of 1100 kW, RD-9F and RD-45 with the power of 1300 and 1400 kW, (totally 18 Russian models with the power up to 100 mW). Success of a range of such leading foreign companies as General Electric and Westinghouse (USA), Kraftunionwerke (FRG) as well as of Russian companies and the companies from other countries in the sphere of gas turbines engineering for the last 10-15 years results from wide use of technical achievements of the serial aviation gas turbines engineering and foremost of the principle of a block standardized design. Serial production requires compulsory thorough economical and technical preparation, optimization of design, patent clearance and common level of equipment and technology since time is needed for production and realization of a series for compensation of expenses and failure may result in high economic losses.

The low-power GTU have rather various designs. The Russian-made GTU design given below is characterized by complexity and large mass, besides the turbine drive occupies approximately one third of the unit by mass and volume (Fig. 1).

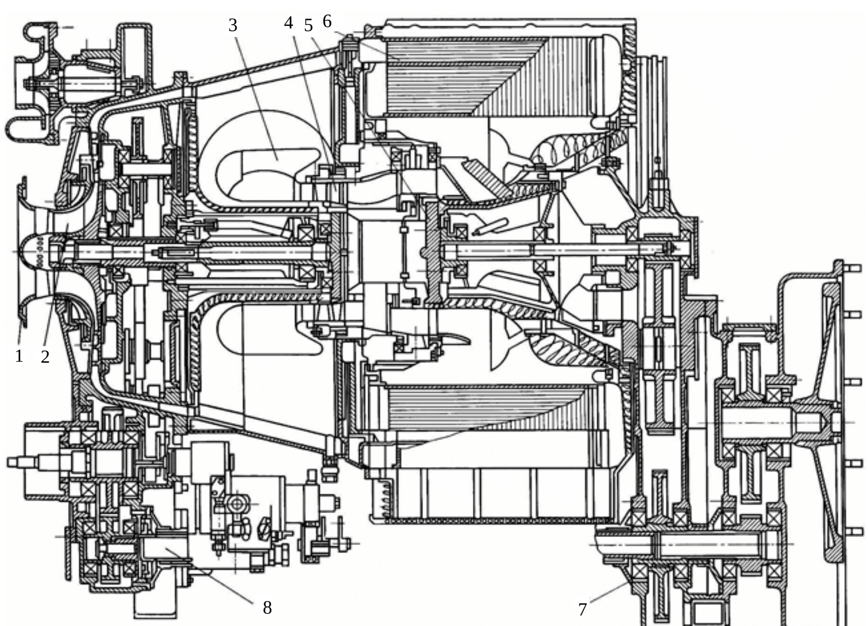
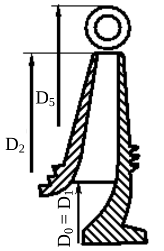
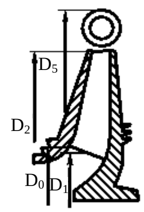
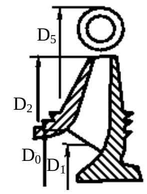
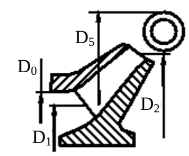
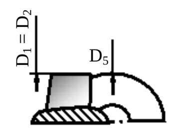


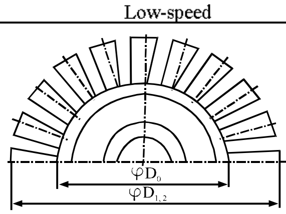
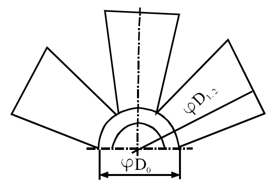
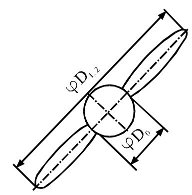
Fig. 1: General view of a GTE (Gas-Turbine Engine) with a built-in heat exchanger and a reducer: 1: input tubes, 2: centrifugal compressor, 3: combustion chamber, 4: compressor axial turbine, 5: axial power turbine, 6: ring heat exchanger, 7: reducer, 8: gearbox (Technical characteristics: Capacity (kW) = 270; Specific fuel consumption (g/kW·h) = 1.10; Air consumption (kg/c) = 41.0; Gas pressure (mPa) = 0.152; Output gas temperature (°C) = 540; Length (mm) = 1440; Width (mm) = 1170; Height (mm) = 1088; Weight (kg) = 800)

Table 1: Types of driving wheels by criterion of rapidity

Parameters	Low speed	Normal	High-speed	Diagonal	Axia
	⇐Centrifugal				
Appearance					
n_s	40-80	80-150	150-300	300-600	800-1200
D_2/D_0	2.5	2.0	1.8-1.4	1.3-1.1	0.8
D_s/D_o	5.0	4.0	3.0	2.0	1.0
ψ	1.5-1.2	1.2-0.9	0.9-0.6	0.6-0.20	0.3-0.25
φ	0.03-0.07	0.07-0.11	0.11-0.15	0.15-0.20	0.2-0.25
η	0.70	0.75	0.80	0.85	0.90
π_w	4.0-7.0 (14)	2.5-4.0	1.5-2.5	1.5-2.0 (4)	1.1-1.35 (2.0)

$n_s = 53\omega Q^{1/2}/H^{3/4}$: specific velocity ($\omega$: angular speed, Q: productivity, H: pressure); $\psi = C_r/u_2$: pressure factor (C_r: flow radial speed at the wheel output, u_2: wheel angular speed); $\varphi = C_2/u_2$: consumption factor (C_2: final speed of a stream at the output); η = driving wheels efficiency and π_w = pressure ratio

Table 2: Elaborated classification of the axial rotor wheels depending on specific speed

Parameters	Low-speed	Normal	High-speed
Appearance			
n_s	800-900	900-1000	1000-1200
D_2/D_0	up to 3	up to 6	up to 12
ψ	0.3	0.2	0.1
φ	0.22	0.24	0.26
η	0.91	0.92	0.93
Z	80-10	10-6	4-2
π_w	1.25-2.0	1.2-1.35	1.1-1.2

$n_s = 53\omega Q^{1/2}/H^{3/4}$: specific velocity ($\omega$: angular speed, Q: productivity, H: pressure); $\psi = C_r/u_2$: pressure factor (C_r: radial speed of a streamat the wheel output, u_2: angular speed of a wheel); $\varphi = C_2/u_2$: consumption factor (C_2: final speed of a stream at the wheel output); η = driving wheels performance; π_w = pressure ratio and Z = number of blades

The turbines structural design is of crucial importance for their properties. Table 1 shows improved classification of turbine compressor rotor wheels according to a specific speed criterion, the classification evidences that the rotor wheels specific speed, i.e., equivalent number of rotations necessary for achievement of the required pressure, may vary 30 fold.

The wheels classification by specific speed as given in Table 1 provides detailed classification only for centrifugal wheels. However, axial wheels are as well widely used in industry though they do not have a special classification. We offer classification for the axial wheels similarly to that for the centrifugal (Table 2). The number of blades of the axial wheels is the principal classification factor since it has great importance for selection of calculation methods and structural design of the axial rotor wheels (Table 2).

High-pressure axial-radial wheels with low-level low speed were used in the aircraft engines of the first generation (Fig. 2). Later preference was given to the axial wheels with the ductal designs more optimal for application in the aviation industry. In the recent years, the axial-radial wheels come into use in the stationary centrifugal compressors and allow achieving high pressures. The low-speed wheels have low performance coefficient and maximum achieved pressure ratio of the low-speed wheels used in aviation may reach $\pi_w = P_R/P_W = 14$. This ratio has the performance coefficient of 0.70. The 10 axial stages of GTU compressor applied nowadays have the total performance coefficient equivalent to 0.348 (given the maximum performance coefficient of 0.90).

Modern designs both of home and foreign low-power GTU use magnetic bearings and the shaft of the power

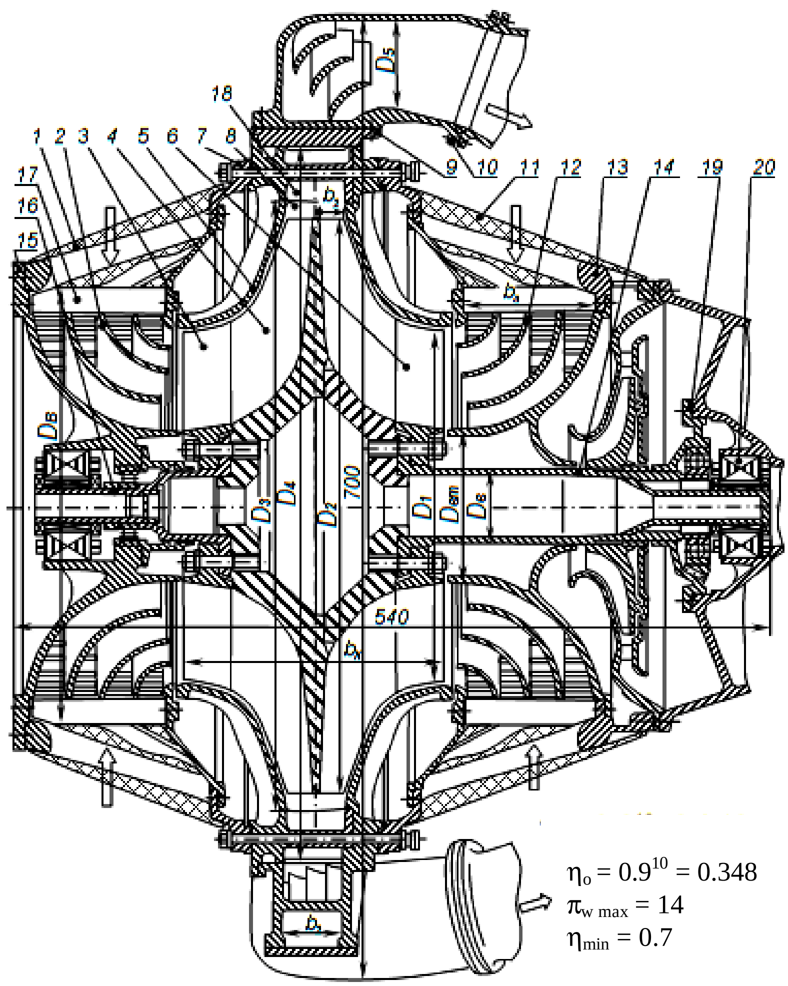


Fig. 2: The centrifugal compressor with magnetic bearings, BSTU configurations; 1 and 11: protective grid; 2 and 12: splitter ring of intake duct; 3 and 6: rotating Directing Device (DDW) and heels, compressor; 4: heel; 5 cover of compressor case; 7 and 13: heavy-duty frame structure; 8: vaneless diffuser; 9: compressor case; 10: combustions chamber inlet duct; 14: rear-end pin; 15: front-end bearing case; 16: front-end pin; 17: vane of motionless directing device (HHA); 18: vaned diffuser, 19: adjusting ring and 20: magnetic bearing

turbine set is connected directly to the generator which eliminates necessity in complicated and fire-hazardous lubrication system and results in enhancement of reliability, working capacity and technical parameters of the unit (Patent 2064813, 2010; Komarov, 1994; Schweitzer *et al*., 1994; Carrere *et al*., 1994; Zhuravlyov, 2000; Lin, 1993). Use of the magnetic bearings allows automatic rotor balancing during operation, setting of optimal and almost any required speed rate upper limit of which is restricted by mechanical strength of the rotor materials which is typical for the low-power turbines (Nonami and Ito, 1994; Schob and Bichsel, 1994; Shpak, 1995; Truston, 1991; Voronkov and Denisov, 1994; Williams *et al*., 1994).

In some micro-turbine designs the rotation speed reaches 10^5 rpm, i.e., use of the magnetic bearings in GTU notwithstanding rather high cost of the same is fully justified due to several factors inclusive of those having relation to speed (Zhuravlyov, 1998, 2000; Andrejev, 1994; Biswas and Ishizuka, 1995; Childs and Noronha, 1999).

High level of automation is also a valuable factor for reliability improvement of the home GTU, it enables remote control and diagnostics of the units through a unified control and diagnostics center by highly-qualified specialists (Fig. 3). The magnetic bearings parameters are shown in the center of the screen.

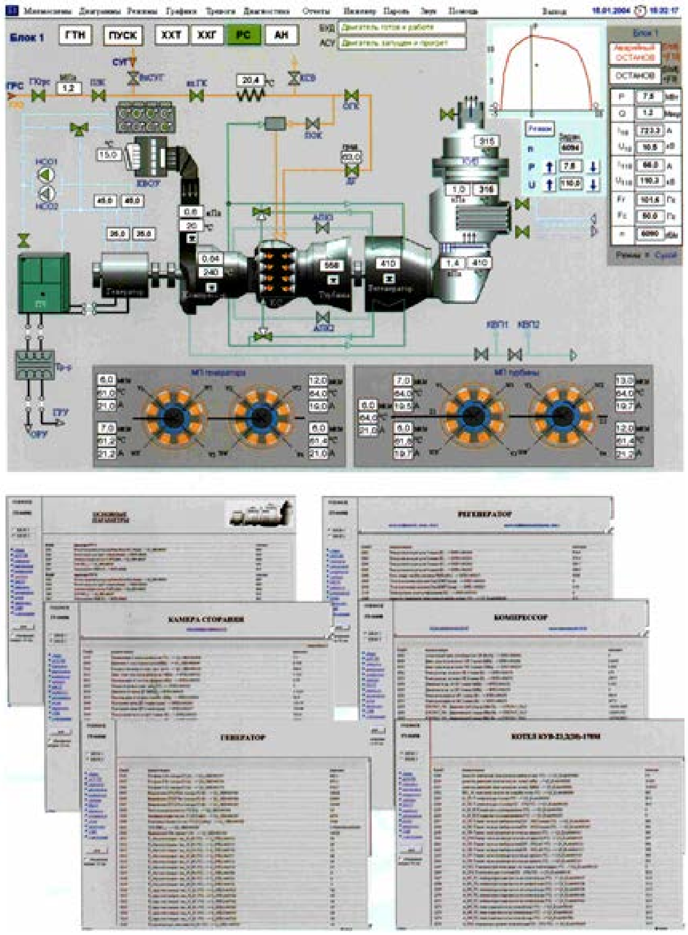


Fig. 3: General view of the working screen for control of the gas turbine unit key parameters

Rise of temperature inside a turbine results in increase of its efficiency but the turbine materials are affected by severe speed, vibration and temperature conditions. The foreign researchers state that ceramic materials demonstrate good temperature resistance nevertheless the same are characterized by low mechanical strength and high fragility resulting in low vibration resistance. Sintered metal powder materials have higher performance, however, they have similar poor plastic properties and their processing is rather complicated.

Composite designs of blades and turbine wheels with additional processing, for example coating of heat-resistant metals in the standard design turbines with metal ceramic materials by plasma spraying demonstrate good prospects. Thus for example use of glassceramic coating allows to increase the operating temperature of the GTU blades from 1350-1800°C which enables the turbines performance coefficient increase by 10%. Due to absence of the necessary materials the turbine blades are required to be cooled which results in worsening of their parameters. At the recent years, the turbine blades are cooled also by water injection directly into the wheel space which leads to several positive effects: gas temperature goes down with simultaneous extension of its volume up to two times, change of gas aggregative state results in the heat transfer factor growth by hundreds of times, i.e., the turbine performance is being increased. High temperature causes partial water decomposition accompanied by separation of oxygen and hydrogen, which also increases the GTU production capacity and in combination with multi-stage combustion allows for postcombustion of nitric and carbonic oxides which in its turn results in enhancement of the GTU environmental characteristics by up to 2 and sub-sequently by more times as compared to the immediate competitive (diesels).

The low-power GTU in the PPTP plants simultaneously operates directly as a power agitator with the preset high degree of incoming air purification provided by GTU design. Thus, for example the turbo-blower design

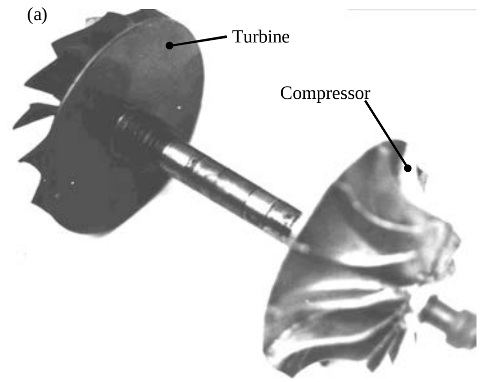


Fig. 4: a) Gas turbine rotor and b) General view of gas turbine

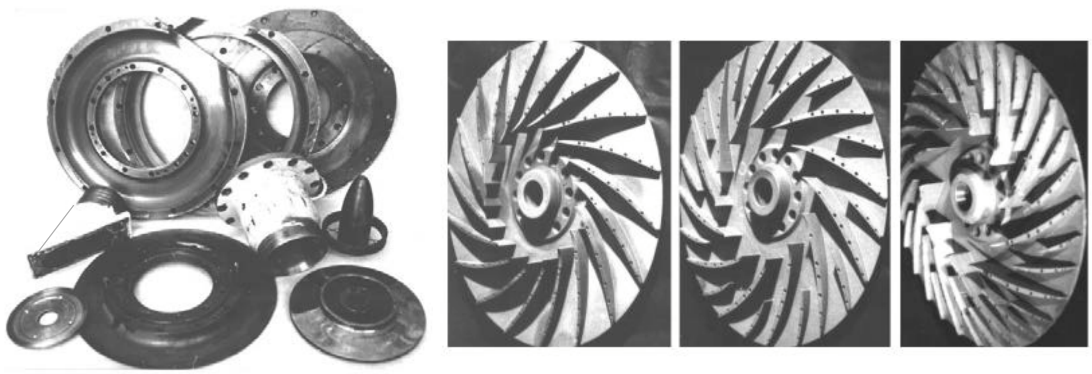


Fig. 5: Complete set of BSTU supercharger parts

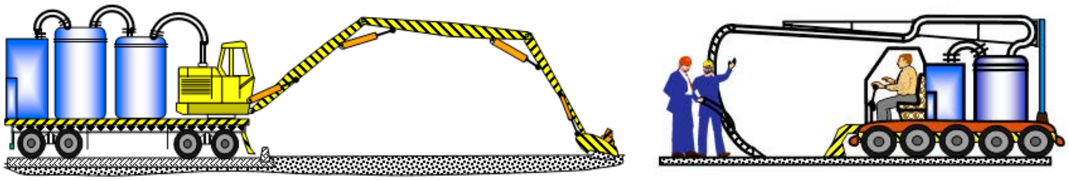
elaborated by BGTU on the basis of the series-produced supercharging turbo-compressor for diesels is shown on Fig. 4. Turbo-blowers with simple structure design enable cost-effective control modes depending on the dust load level and consequently ensure reduction of energy consumption by a dust handling system by up to 2 times. The blower was designed with use of a high technology which applies high speed allowing achieving high efficiency and pressure within one stage, a flexible shaft enabling the rotor autobalancing for removal residual unbalance. The blowers equipped by a turbine drive have centrifugal wheels produced by almost waste-free brand new permanent mold casting methods with use of investment patterns which results in two-order reduction of weight and production labor intensity of the wheels and the blower itself as compared to the blowers of other types. Reduction of a finished product weight by 1% results in reduction of its production costs by 2%.

Development of a low-power GTU with use of serially produced modules is several tenfold more cost-effective then development of the powerful units and involves less economic risks. Figure 5 shows the test bench parts and the rotor wheels made in BGTU under minimum possible financing conditions. The rotor wheels were subjected to tests which confirmed their high efficiency.

Direct connection between the generator and the turbine eliminates necessity to use an expensive and unreliable high-speed step-down reduction gear, results in considerable simplification and cheapening of design and use of the magnetic bearings allows elimination of an Inflammable Lubrication System.

Use of a low-power GTU complete with a pneumatic drive utilizing air as an energy carrier suggests new economic and constructive perspectives. When air is used in a drive the drive is becoming safer, its material content and production cost is getting several fold lower, its design is being changed towards simplicity. Multiple power conversion causing additional losses due to conversion of gas energy into electrical and then into mechanical energy is no longer required, therefore, there is no need in a generator, a frequency converter and a reduction gear the cost of which in aggregate may constitute >50% of the gas-turbine unit value.

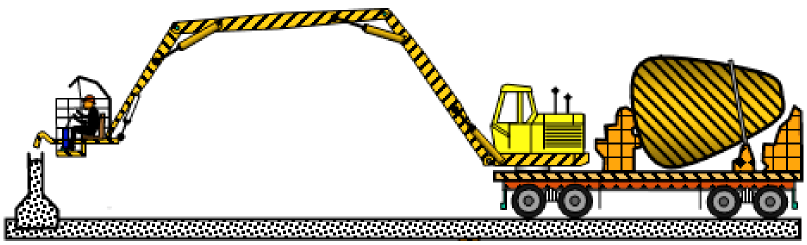
Use of the low-power GTU is especially advantageous for the Portable Pneumatic Transportation



Roads and territories productivity 40 t/h

Premises productivity 40 t/h

Fig. 6: Portable Pneumatic Transportation Plants (PPTP)



Roads and territories productivity till 50 t/h

Fig. 7: Cars for repair of roads and constructions

Plants (PPTP) being developed by the Chair of Heat Technology Energetics of BGTU Named after V.G. Shukhov shown on Fig. 6 and 7. The PPTP for internal and external volumetric cleaning could be reasonably used as well for external and internal renovation of the premises which allows to mechanize the majority of renovation operations, to advance its quality and achieve additional profit due to higher efficiency and quality of renovation activity.

PPTP are a part of a widespread pipeline transport. Currently traveling pipeline plants having portable branched pipelines are represented solely by concrete pumps. It is offered to extend the above series by a range of Portable Pneumatic Transportation Plants (PPTP) and to apply a new designation for the whole class of the mentioned machines Portable Pipeline Plants (PPP). Overall view of the portable pipeline plants is given on Fig. 6 and 7. Overall view of a recommended waste processing plant is shown in Fig. 8a. Timely collected dry vegetable remains from the adjoining territories are valuable raw materials for production of new environmentally safe construction materials like wood chipboards (fiberboards) or wood concrete (Fig. 8b).

RESULTS

Realization of technical capabilities of the modern mobile pneumatic transportation plants is not possible without new technical solutions, materials, equipment, automation systems, production and maintenance technologies, electronic equipment, qualified personnel, i.e., without achievements of the scientific and technological complex of our country as well as without a political will for their implementation and support towards a domestic manufacturer and science.

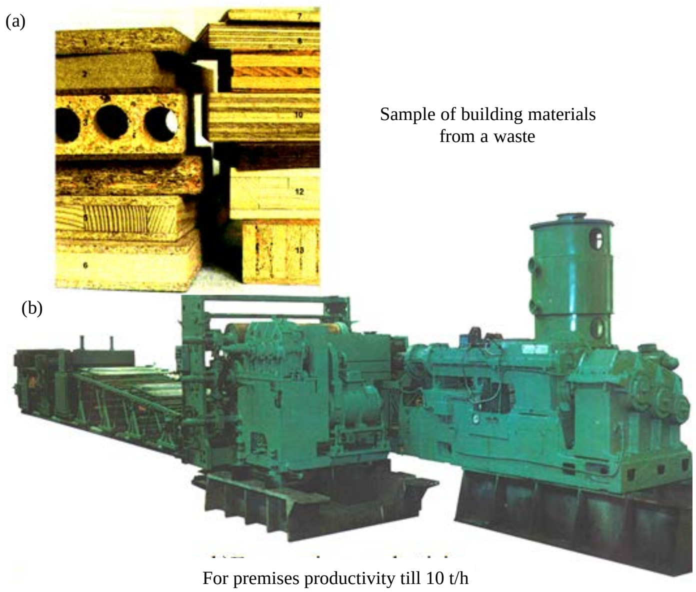


Fig. 8: A low-tonnage manufacture line with a waste processing capacity up to 1 t/h

CONCLUSION

The offered devices for cleaning of premises and adjoining territories enable both mechanization of the manual cleaning process and application of the secondary wastes recycling technology which will allow having an extra profit on their use. Timely collected dry vegetable remains may be used as valuable raw materials for production of environmentally safe materials like wood chipboards, wood fiber boards or wood concrete. The offered equipment may be used for creation of a low-energy-intensive energotechnological environmentally safe complex for construction and repair of the premises and other buildings from concrete or gas concrete by an advanced method of a continually moving shuttering. The system allows to eliminate the operations of production, transportation, stacking of reinforced concrete products or bricks, to implement various architectural solutions for layout planning, external and internal finish as well as to reduce costs and terms of construction. New method of casting into a continually moving shuttering significantly expands opportunities, promotes casting quality and reduces shuttering expenses, enables mechanization and ultimately automation of the construction process. The system may be used for opening and filling of cracks on roads and roofs with a special compound. The mobile pneu matic transportation plants are unexpendable in case of necessity to eliminate consequences of accidents and catastrophes as well as for nanocovers application and removal.

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