Computer model of a gas path in a microturbine unit

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Abstract. Microturbine units are used for autonomous supply of buildings and engineering facilities with heat and electric energy. Gas path of a microturbine unit contains a combustion chamber and a set of gas-burners which provide mixing of the natural gas with the air, followed by total combustion of the obtained gas-air mixture. The known structures have two essential disadvantages which reduce operational efficiency of a gas turbine as part of the microturbine unit. The first disadvantage is caused by inhomogeneous nature of the "gas-air" flammable mixture, which leads to an incomplete combustion of fuel and emission of nitrogen oxides harmful for the environment. The second disadvantage is connected with a loss of mechanical strength of structural elements exposed to the impact of high-temperature products of combustion. The article proposes methods of boosting the resource of a combustion chamber by enhancing its mechanical durability with a simultaneous reduction of the content of nitrogen oxides in flue gases. The first method is in the use of power elements installed inside the combustion chamber. The second method of boosting the resource of the combustion chamber is connected with accurate profiling of windows through which cylindrical gas-burners get inserted. The third method is based on improving the quality of mixture formation in the casing of the gas-burner. Combined application of the proposed modification activities allows reducing the extent of harmful emissions as well as boosting the resource of the microturbine unit. Keywords: annular combustion chamber, swirl burner, geometrically accurate profiling, curve of the second order of smoothness, loss of stability.

1. Introduction

Gas path of a microturbine unit contains a combustion chamber and a set of gas-burners. Gas-burners provide mixing of the natural gas with the air, followed by total combustion of the obtained gas-air mixture. Annular combustion chamber of CapstoneC-200 gas microturbine unit produced in the USA is a reverse-flow chamber which provides transformation of chemical energy of gaseous fuel into the heat energy of the operating body [1]. Annular combustion chambers are the lightest and compact; they are placed between the compressor and the operating wheel of the turbine's rotor (Figure 1).

The known combustion chamber has a number of essential disadvantages which reduce operational efficiency of a gas turbine:

1. In homogeneous nature of the "gas-air" flammable mixture lead stoan in complete combustion of fuel and emission of nitrogen oxides which are harm ful for the environment [2].

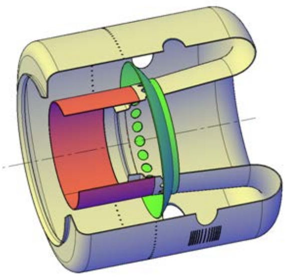

Figure 1. Annylar combustion chamber of Capstone C -200.

Figure 2. Deformation of the combustion chamber.

2. Under prolonged exposure to high-temperature products of combustion, the strength and elasticity module of a heat-resistant alloy decreases, which has a negative effect on mechanical stability of the combustion chamber's shell [3]. Pressure surges, caused by a rapidly moving front of the flammable mixture at switching on or switching off the combustion chamber, results in deformation of its thin-walled cylindrical shell (Figure 2). At that, mutual position of elements of the gas path gets disordered and causes failure of the entire microturbine unit. Calculation shows that the loss of stability of the external cylindrical shell of the combustion chamber might occur under exceedance of the outer pressure over the internal pressure for the value Δp~375 kPa [4, 5]. The article proposes methods of boosting the resource of the combustion chamber by enhancing its mechanical durability with a simultaneous reduction of the content of NOx nitrogen oxides in flue gases.

2. Application of mechanical power elements

The first method of boosting the resource lies in the use of mechanical power elements. An improved combustion chamber contains hollow perforated heat-resistant braces of adjustable length, which ensure additional stiffness of the structure. The braces are placed between the belts of gas-burners and therefore they provide not only reinforcement of the casing but also local cooling due to incoming fresh air. Fresh air delivery through the hollow perforated braces provides total combustion of fuel, reduces temperature of combustion products and therefore reduces formation of NOx nitrogen oxides in flue gases. The reinforced combustion chamber (Figure 3) contains a cylindrical thin-walled outer casing 1 made of heat-resistant metal or alloy, and a cone-shaped thin-walled inner casing 2 in the form of a funnel for an exhaust of burnt flue gasesat the output of the turbine's rotor wheel. Outer and inner casingparts of the annular combustion chamber get conjoint by toroidal surface 3 made of a thin sheet of heat-resistant alloy. Outer casing of the combustion chamber has reach-through windows 4 of a complex form intended for installing of cylindrical gas-burners inside of them (at the angle of 45 degrees to the axis of the combustion chamber). The number of windows corresponds with the number of gas-burners. The casing assumes the presence of hole 5 intended for installing a spark plug. The brace positioned inside the combustion chamber consists of tube 6, formed washer 7 and adjusting threaded bush 8. Alteration of the brace's length is carried out by rotating the bush 8.

A distinctive feature of the first method of boosting the resource of the combustion camera is in the fresh air delivery straight to the combustion chamber through the holes in hollow perforated braces.

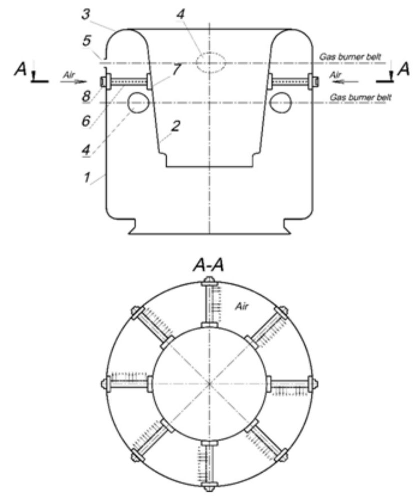

Figure 3. Annular combustion chamber, reinforced with braces.

3. Geometrically accurate profiling of a window of the gas-burner

Thesecondmethodofboostingtheresourceofthecombustionchamberisconnectedwithaccurateprofilingof windowsthroughwhichcylindricalgas-burners get in serted. In order to eliminate ejections of flame, it is necessary to ensure the minimal clearance between the combustion chamber's shell and the gas-burner's casing. Minimization of the clearance gets obtained by an accurate geometrical profiling of the window [6, 7]. Theoretical profile of the window is a quartic curve which has decomposed into two closed spatial curves of a complex form [8-11]. Methods of descriptive geometry [12-16] and computer graphics [17-20] allow performing approximation of the theoretical profile by elliptical arcs, interconnected by a second-order smoothness (Figure 4, left). Based on the information obtained, control program gets drawn up for the waterjet machine, and windows get cut in the combustion chamber (Figure 4, right).

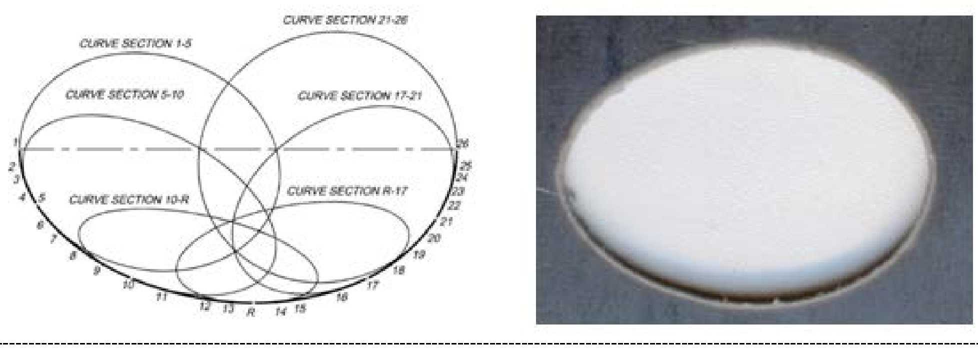

Figure 4. Profiling of a window by arcs of conic sections: design profile and a photo.

The construction of the curve of the second order of smoothness is solved as follows. We need to draw a line of the second order of smoothness formed by the arcs of the second-order curves through the given set of points. The constructed line should not contain inflection points. This means that any triangles formed by three consecutive points of a given set must have the same direction of circumvent. If this condition is satisfied, through specified points we can draw a compound curve of the second order of smoothness formed by the arcs of the second-order curves [19,20].

Let the first curve segment be defined by points 1, 2, 3 and tangents t_1, t_3 (Figure 5). The second segment is defined by point 4 and tangent t_4. At point 3, it is required to ensure the connection of the segments with the common radius of curvature. Through points 1, 2, 3 it is possible to conduct a single conic a^2, satisfying the conditions of tangency t_1, t_3. We find its circle of curvature r in point 3. The second bypass segment b^2 is set by a circle of curvature r and point 4 with the tangent t_4 indicated in it. We find satisfying these conditions the conic section b_2. At point 3, we obtain a three-point touch of curves a^2, b^2. This is the touch of the second order of smoothness. The ellipse b^2 intersects r at triple point 3 and at point B. The curve a^2 intersects the circle of curvature r at the same triple point 3 and at point A.

According the considered algorithm was to build a convex compound curve of the second order of smoothness formed by arcs of ellipses is constructed (Figure 4). The compound curve has common circles of curvature at abutting points 1, 5, 10, R, 17, 26 and passes through the previously found points 1...26. The second part of the profile is formed by mirroring the curve of line 1... 6 relatives to the axis of symmetry

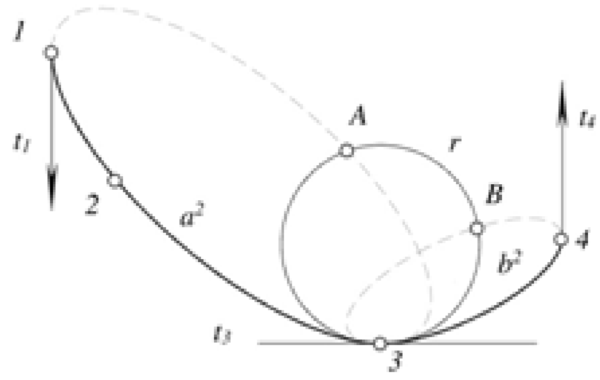

Figure 5.Conjugation of the second order of smoothness.

Thus, the theoretical profile of window consists of six segments of ellipses interconnected of smoothness of the second order. Using the “properties” command of the AutoCAD graphics suite is determined the coefficients of canonical equation of each of the six ellipses. Based on the obtained information, we compile a control program for the water jet machine and cut out windows on the evolvent of the combustion chamber.

4.Improving the quality of mixture formation

The third method of boosting the resource of a microturbine unit’s operation is connected withimprovingthequalityofmixtureformationinthecasingofthegas-burner. The known injector gas-burners are characterized by an expensive cost, small resource and a high level of environmentally harmful emissions of nitrogen oxides. Therefore, using swirl injector burners with compulsory air supply seems to be reasonable. Among advantages of such gas-burners are their small size, the ability to burn a big amount of gas, and the absence of noise. The mixing chamber, in which preparation of the gas-air mixture takes place, is of a small volume, and the outing speed of the mixture reaches 50 meters per second. As a result of the analysis, the following variants of swirl-type injector gas-burners were singled out: gas-burners with multi-stage burning, with a separating nozzle grid, and with an injector for spraying the gaseous fuel in the form of a Laval Nozzle [21]. The swirl-type injector burner with multi-stage burning which supplies saturated water vapor to the burning zone (Figure 6) is offered as the most perspective variant. Compressed air mixed with the water vapor is delivered through special input 1. The main flow of the air passes through vanes 2, inclined to the axis of the flow at the angle of 45 degrees. The air flow becomes turbulent. Natural gas gets delivered through small-diameter holes in injector head 3. Gas jets get mixed with the air and then inflame. Compulsory supply of compressed air and vapor directly to the burning zone (through tube 1) allows reducing the content of nitrogen oxide in products of combustion.

Another type of a gas-burner contains separating nozzle grid 1 (Figure 7). Preparation of the fuel mixture takes place in the mixing chamber between plug 3 and grid 1. The mixing chamber is isolated from the burning zone, which excludes the possibility of a backfire (opposite to the direction of the fuel mixture's movement). Vanes 2 provide turbulation and swirling of the air flow, which gets delivered to the mixing chamber. Calculation and plotting of trajectories of the moving fuel particles is carried out on the basis of means and methods of descriptive geography and computer graphics [20-26].

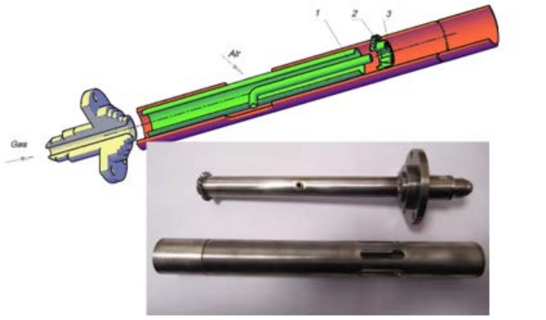

Figure 6. Gas-burner with a vapor-air tube.

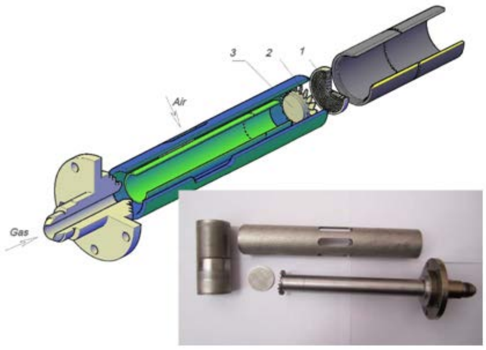

Figure 7. Gas-burner with a nozzle grid.

5. Conclusion

Combined application of the proposed modification activities allows essentially improving the main technical characteristics of a microturbine unit as well as boosting its resource and reducing the extent of harmful emissions. Experimental testing of operating ability of the improved gas-burners proved their workability in the given range of heat power. Consumption of combustion gas has reduced which proves a more complete combustion of fuel. The proposed method of improvement of annular combustion chambers, applicable to combustion chambers of gas microturbine units, has no analogs around the world, including the firstlyused engineering elements and processing methods with creation of a new physical-and-chemical effect of reducing the NO_X emission due to the delivery of additional fresh air (oxidant) directly to the combustion chamber, bypassing the injection gas-air burners. The described engineering regime-process approach will allow enhancing the efficiency and reliability of combustion chambers. It will also provide a total burn-out of fuel with simultaneous reduction of the temperature of combustion products and reduction of NO_Xemission, as well as it will reduce or completely eliminate the warp distortions of combustion chambers.

6. References

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