



No-moving-part commutation of gas flows in generating plasma by cumulative detonations (survey)



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ABSTRACT

This paper surveys controlling, without use of mechanical valves, of flows of three gases: a combustible mixture (fuel and oxidant), combustion products, and a neutral scavenging gas. The gases are delivered periodically in an alternating way into a pair of pulsed MHD electricity generators. Essential problem of this type of electricity generation is insufficient ionisation level of combustion products in the usual deflagration type burning. Solution was found in achieving momentarily extremely high temperatures by cumulative detonations. In the 1st phase the cavities leading into the 1st MHD generator are filled with the combustible mixture, which is then ignited, generating a high-temperature high-speed detonation wave moving into the generator. In the subsequent 2nd phase the combustion product are scavenged in the cavities by the neutral gas. In the other generator the phases are in reversed order. Because of the extreme temperature, the flows are switched not by mechanical valves but by no-moving-part devices, in various configuration that are systematically surveyed.

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1. Introduction

Despite the contemporary large progress in renewable electricity production, the largest percentage of the generation processes still relies on burning various fuels. The generation consists of conversion steps with the typical sequence as follows:

- (1) fuel combustion,
- (2) steam generation in a boiler,
- (3) accelerating the steam in turbine,
- (4) generating mechanical power on turbine shaft, and
- (5) electric current generation in induction coils.

Each of these steps is inevitably associated with some energy loss - so that, together with the Carnot cycle limit, the overall efficiency is low. Typically it is not above 35–40%. There is a generally known but practically not used alternative — the magnetohydrodynamic (MHD) generators. They avoid the above processes (2), (3), and (4), thus offering in principle a substantially better conversion efficiency. The original idea is described in Ref. [9] and the present state of art is surveyed in Ref. [11]. The principle requires heating the gas to temperature levels so high that the it is ionised and thus becomes electrically charged. Unfortunately, those few MHD facilities so far built for feasibility tests [11], all fail to reach the necessary ionisation temperatures. Various attempts at efficiency improvement, such as supplying pure oxygen or alkali metal particles to the combustion process, are highly un-economical.

A substantially higher temperatures than now achievable - and consequently much higher degree of gas ionisation - may be reached by replacing the standard deflagration combustion by detonations. It is an idea that has not been so far followed because of the danger associated with very high mechanical stresses of the generator components. Moreover, even the degrees of ionisation achieved in the investigated detonations so far remain below the necessary level.

A solution is offered in Ref. [17]. The basic idea is the cumulative implosion [4,14] inside the combustion chamber, Fig. 1. The temperature in the focal point of the colliding detonation waves is extraordinarily high, as is demonstrated by the military applications in the hollow charge weapons — and yet the stress levels in the chamber walls are not particularly high because of mutual cancellation of oppositely acting forces in the focal point [18]. The military hollow charge concept cannot be simply taken over for electricity generation. It is suitable for a single detonation of solid

explosives — while for the use in a MHD generator the detonations are to be in the gaseous phase and periodically repeated.

This requires a rather complex system (seen schematically represented in Fig. 1) ensuring the synchronisation of colliding detonation waves coming towards the focus from all directions — and also scavenging the combustion products from the cavities after each detonation followed by re-filling by a fresh combustible mixture.

To achieve the mutual cancellation of the opposing forces, the implosive wave inside the combustion chamber has to be generated in a spherical configuration very accurately — apart from the exit into the MHD generator. The necessary very small deviations from the sphericity are practically impossible to achieve with a large number of independent detonation sources on the outer wall of the combustion chamber. There are two reasons: (a) the extremely high speed of detonation waves propagation (always much faster than local speed of sound) and (b) uncertainties associated with the initiation of detonation waves. The latter fact is due to the character of deflagration-to-detonation transition. It depends on turbulence, which is a stochastic phenomenon with substantial uncertainty. Experience has shown that the required accuracy of the spherical symmetry is practically achievable only with a single detonation source — the detonation tube in Fig. 1 — with its output distributed into the large number of parallel equal-length channels. As a result, the necessary geometry of the cavities is rather complex.

The removal by neutral gas of the combustion products from these complex cavities and their replacement by a fresh combustible mixture is achieved by gas flows - combustible mixture and neutral gas — each available from an external pressurised source. The order of their flows and their directing into the combustion chamber must be controlled by a commutator system. Because of the high temperature environment, mechanical commutator valves with moving components are out of question, especially due to preferable operation at the standard 50 Hz repetition frequency (Fig. 4) of the generated alternating electric current. The solution discussed in this paper is based on commutation by no-moving-part devices, made of a refractory material.

2. Generating plasma

2.1. Cumulative effect

The cumulative effect of imploding detonation waves is capable of generating a plasma flow with high degree of ionisation at very high, hypersonic velocities. Both properties are desirable in the MHD generator. The high velocity is achieved by the axial imbalance of detonation waves, with the distributor channels missing on the right-hand side in Fig. 1, where there is the entry into the MHD generator. Existing literature discusses Mach numbers of the detonation wave propagation of the order $Ma \approx 4-8$ [14,16,24].

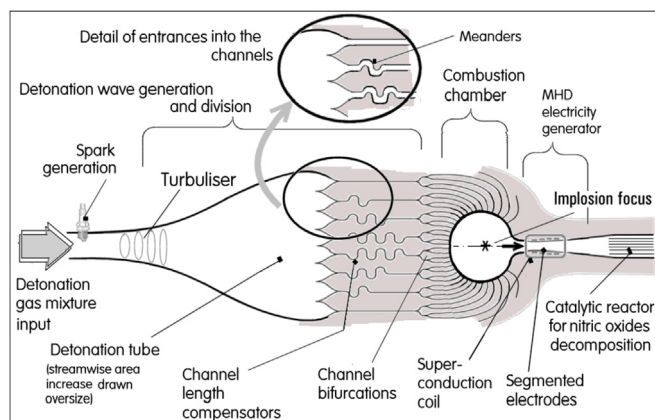


Fig. 1. Schematic representation of the plasma generation by implosion detonations in the combustion chamber. Generated in the tube at left, the detonation wave is distributed through the large number of equal-length channels into wavelets all colliding mutually in the focal point.

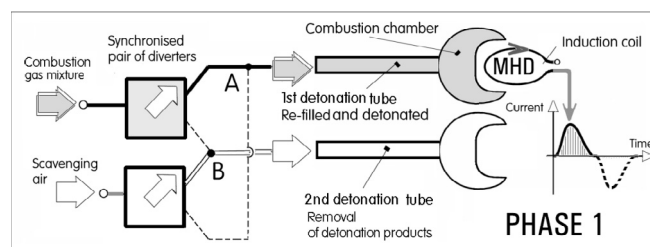


Fig. 2. Principle of generating the alternating current in a pair of MDH generators. Detonations are controlled by two synchronised diverter valves. The 1st detonation tube is here shown filled by combustible mixture through the node A while the 2nd tube is scavenged by air flow delivered through B.

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