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SONIC PRESSURE WAVE GENERATOR

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Fig. 1.

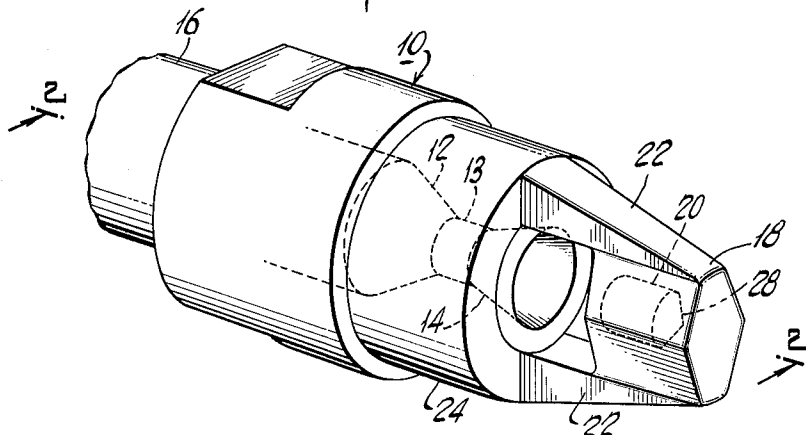


Fig. 2.

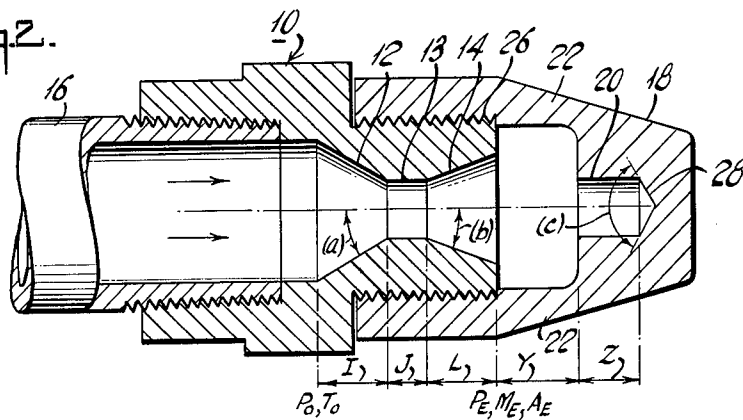
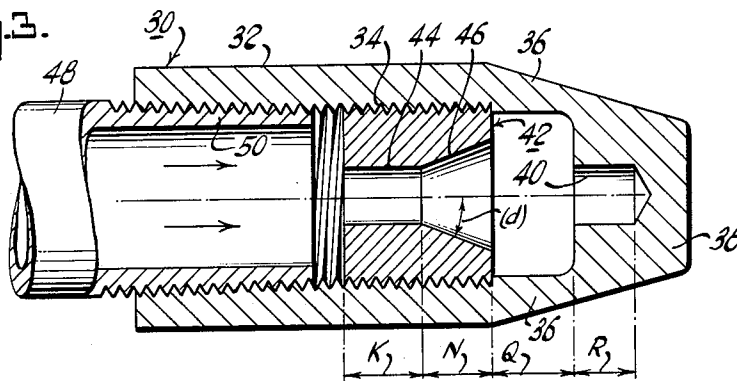


Fig. 3.



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SONIC PRESSURE WAVE GENERATOR

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This invention relates to apparatus for generating pressure waves in fluids; and more particularly, to improved apparatus utilizing the flow of gases to generate "sonic" pressure waves in gaseous media.

This invention constitutes an improvement over the invention disclosed in my co-pending application for United States patent Serial No. 239,236, filed on November 21, 1962, which application is hereby incorporated in and made an integral part of this description.

Briefly, sonic generators in accordance with the above-mentioned co-pending application utilize a converging-diverging nozzle supplied with a pressurized gas to create a high-speed, low-pressure, gas jet which is directed into a cavity pulsator to create a sonic pressure wave output. While such generators provide performance which is substantially better than that of generators previously available, generators in accordance with the present invention provide even further improved performance.

Problems to which constant attention must be given in constructing sonic generators using converging-diverging nozzles are the problems of preventing undue growth of the boundary layers, and of preventing separation of the gas from the interior walls of the nozzle. These problems are especially troublesome in the diverging-section of the nozzle where gas velocities are high. If these problems are not solved, performance of the generator in which the nozzle is used is likely to be unstable, particularly when operation is desired over a relatively wide range of gas input pressures.

Accordingly, an object of this invention is to provide a gas-operated sonic generator having a high-velocity-gas jet-producing nozzle of simple construction which readily maintains such a flow in the boundary layers of gas at the interior surfaces of the diverging section of the nozzle as to minimize the growth of these boundary layers and retard separation of this gas from these surfaces.

Another problem met in the construction of sonic generators using such high-velocity-gas jet-producing nozzles is that the location and dimensions of the shock waves produced at the nozzle's exit often change with any variations that might occur in the pressure of the gas supplied to the nozzle. Since, for optimum performance, the size and location of the pulsator unit with respect to the nozzle depends upon the dimensions and location of these shock waves, these changes create undesirable changes in sonic power output and efficiency of the generator as input pressure is varied.

Accordingly, another object of this invention is to provide a sonic generator incorporating a high-speed, low-pressure-gas jet-producing nozzle which produces shock waves at its exit which are stable in location and have relatively unchanging dimensions throughout a relatively wide range of variations of input pressure.

A further object of this invention is to provide such a generator which is of a simple construction and is economical to build and operate.

A still further object of this invention is to provide a gas-operated sonic generator of such construction as to produce a sonic pressure wave output having frequencies falling within a narrow range and having a minimal amount of extraneous noise.

Other objects, aspects and advantages of the present

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invention will be pointed out in, or apparent from, the following description and drawings, in which:

FIGURE 1 is a perspective view of a gas-operated sonic pressure wave generator embodying the present invention;

FIGURE 2 is a sectional view of this generator taken along line 2—2 of FIGURE 1, in the direction of the arrows; and

FIGURE 3 is a sectional view of another gas-operated sonic wave generator embodying the present invention.

The gas-operated sonic wave generator shown in FIGURES 1 and 2 comprises a nozzle portion, generally indicated at 10, having a converging inlet section 12, an essentially cylindrical mid or "stabilizing" section 13, and a diverging outlet section 14. A source of pressurized gas (not shown) is connected through a pipe 16 to one end of nozzle portion 10, and a pulsator unit 18 is attached to its other end. Pulsator unit 18 includes a pulsator chamber 20 which intercepts the gas jet produced by the nozzle 10 and emits sonic pressure waves, all in the manner described in my above-mentioned co-pending patent application.

The provision of the cylindrical stabilizing section 13 joining converging section 12 and diverging section 14 in nozzle 10 substantially increases the stability, and also the power output and efficiency, of the sonic generator in which the nozzle is used. Furthermore, it allows the generator to be operated over a relatively wide range of variations of input air pressure levels without the previously-experienced drop-off in power and efficiency.

It is believed that one reason the addition of stabilizing section 13 creates such improved results is that the flow lines of the gas flowing through the nozzle are straightened in section 13 and are not bent as abruptly as they otherwise might when they pass from converging section 12 to diverging section 14. This creates an overall smoothing effect in the flow which reduces the tendency toward turbulence in and build-up of the boundary layers of gas flowing along the interior surfaces of diverging section 14. At the same time, this smoothing effect reduces the likelihood of the gas separating from the walls of this section.

Another reason for the improvements resulting from the present invention, it is believed, is that this construction prevents the plane at which the gas pressure equals ambient pressure (the "ambient pressure plane") from moving into the converging or diverging sections of the nozzle and thereby causing a deflection of the gas flow which would tend to increase boundary layer thickness and enhance the possibility of separation of the gas from the interior of the nozzle.

A further advantage of this construction is demonstrable when the pressure of the input gas is varied, either deliberately over a moderate range, or due to the pressure fluctuations which might be encountered in the usual industrial pressurized gas supplies. Under such conditions the increased tendency toward separation and excessive boundary layer turbulence caused by such pressure variations is minimized. Thus, the output of the generator is predictable and stable despite such variations in the input pressure, in contrast to the erratic and unpredictable output often developed by nozzles not provided with such a stabilizing section, a lack of stability which, it is believed, may be caused by a shifting of the ambient pressure plane.

This stability and predictability of the output characteristics has, it is believed, several beneficial effects. The overall effect is to provide a generator whose sonic output power is relatively stable and predictable despite the usual fluctuations of pressure encountered in most pressurized gas supply systems used in industry. Also, as suggested above, the sonic output power of this generator can be

effectively varied over a moderate range of output values in a stable and predictable manner by varying the input gas pressure. For example, generators constructed and operated in accordance with this invention give steady and predictable sonic power outputs when operated with input gas pressures varying between approximately 10 and 30 pounds per square inch gage (p.s.i.g.).

Another benefit is that it generally improves the efficiency of these generators, especially generators operating with relatively high input gas pressures in the vicinity of 30 p.s.i.g. For example, generators in which the stabilizing section of the present invention is added to a converging-diverging nozzle have produced at least 50 percent more sonic output power than without such a stabilizing section.

A further beneficial effect is that the frequency of the sonic pressure wave output produced by the generator is "cleaner"; that is, the frequencies produced fall within a band which is narrower than previously obtained with devices of this nature so that the output is more nearly free from extraneous noise.

The explanation of these effects, it is believed, is that this stability and predictability produces a corresponding stability in the dimensions and location of the shock waves in the jet. Thus, it is believed, the longitudinal axis of shock wave remains relatively aligned with the longitudinal axis of the nozzle 10, and the outlines of the wave remain relatively symmetrical with respect to this axis. Also, the distances from the exit end of the nozzle to the points at which the outlines of the shock waves converge remain relatively constant, i.e., they do not fluctuate rapidly or "flutter." Since, for optimum performance of the generator, the pulsator cavity 20 should be located, centered, and dimensioned as precisely as possible with respect to the location and dimensions of this shock wave, a pulsator with fixed dimensions may be used in a generator in accordance with this invention to produce a sonic power output deviating only slightly from optimum values as the input gas pressure varies. Furthermore, the reduction of "flutter" of the shock wave tends greatly to "clean up" the frequency distribution of the sonic output.

The length J of stabilizing section 13 should have a minimum value equal to the axial shift in position of the "ambient pressure plane" that would occur in an ordinary converging-diverging nozzle having converging and diverging sections with the same dimensions as those of the proposed nozzle, when the input pressure varies within certain expected limits. The distance of this axial shift can be determined by using the following equations to determine the nozzle diameters at which the "ambient pressure plane" will appear when first the maximum and then the minimum expected input pressures are supplied, and then computing the axial distance between the points along the nozzle axis at which these diameters are located.

$$(1) \quad \frac{A}{A^*} = \frac{1}{M} \left[\left(\frac{2}{k+1} \right) \left(1 + \frac{k-1}{2} M^2 \right) \right]^{\frac{k+1}{2(k-1)}}$$

$$(2) \quad \frac{P_0}{P} = \left(1 + \frac{k-1}{2} M^2 \right)^{\frac{k}{k-1}}$$

Where:

A = the cross sectional area of the nozzle's conduit at any point along its longitudinal axis.

A* = the cross sectional area of the nozzle conduit at the point where the Mach number of the gas in the nozzle = 1.0.

M = the Mach number of the flowing gas at any point along the nozzle's longitudinal axis at which the nozzle's cross sectional area is A and the pressure of the gas flowing is P.

k = the ratio of specific heats of the gas flowing through the nozzle.

P₀ = the absolute pressure of the gas at the nozzle inlet (stagnation pressure).

P = the absolute pressure of the gas in the nozzle at any point along its longitudinal axis.

In practice, the length J of the stabilizing section 13 is made somewhat longer than the above-described minimum value. The ratio between the length J of stabilizing section 13 and the length L of diverging section 14 usually falls between 1/3 and 1/2. Nozzles using a ratio of J to L of 1/3 have proved especially desirable.

The pulsator cavity 20 in pulsator unit 18 is held in the desired spaced relationship to nozzle 10 by means of a pair of leg-like members 22 affixed to a ring-shaped portion 24 which is attached to nozzle portion 10 by means of screw threads 26. This threaded engagement may be used to provide for adjustment of the distance between pulsator unit 18 and nozzle 10.

The length I and convergence angle (a) of converging section 12, and the length L and divergence angle (b) of diverging section 14 necessary to give a preferred output from the sonic generator all can be determined from Equations 1 and 2 in accordance with the principles set forth in my above-mentioned co-pending patent application. Similarly, the distance Y of the forward end of pulsator cavity 20 from the exit of nozzle 10, and the depth Z of cavity 20 to be used in obtaining optimum performance from the generator may be determined by use of the principles set forth in my above-mentioned co-pending patent application.

The pulsator cavity 20 comprises a cylindrical hole having a conically-shaped rear wall 28. The provision of conical rear wall 28 for cavity 20 improves the performance of the sonic generator in that the frequencies of the sound waves emanating from cavity 20 fall within a substantially narrower band than in previous devices of this nature. That is, the sonic pressure wave output is "cleaner" and contains less extraneous noise.

When this conically-bottomed pulsator is used with a nozzle incorporating a stabilizing section in accordance with the present invention, the strong "clean-up" effect of the stabilizing section combined with the added "clean-up" effect of this pulsator produce a sonic pressure wave output having a highly satisfactory frequency characteristic.

The cone angle (c) of rear wall 28 of conically-bottomed pulsator cavity 20 should be, desirably, between 90° and 150°. An angle of about 120° has proved highly satisfactory in actual use. It is believed that this pulsator cavity bottom intercepts and reflects the shock waves of the gas jet produced by nozzle 10 in a manner such that the development of sonic pressure waves at undesired frequencies is reduced.

The sonic generator shown in FIGURE 3 includes a housing member, generally indicated at 30, which comprises a ring-shaped section 32 with a set of interior screw threads 34, a pair of leg-like members 36 connecting an end portion 38 of housing 30 to threaded support section 32, with a pulsator cavity 40 formed in end portion 38.

A cylindrical nozzle member, generally indicated at 42, is threaded on its outside surface and is mounted inside housing member 30 by engagement with screw threads 34. Nozzle member 42 has an axial passage or conduit which includes an initial straight cylindrical stabilizing section 44 followed by a diverging section 46. A source of pressurized gas (not shown) is connected to housing 30 through a pipe 48 having a threaded end 50 engaged with screw threads 34.

The construction of the generator shown in FIGURE 3 is simpler than that of previous sonic generators. First, the machining of sections 44 and 46 of nozzle member 42 is simpler since member 42 may be prepared as a separate element and can be fitted into housing 30 when it is completed. Additionally, member 42 is constructed without a converging section corresponding to section 12 of the nozzle shown in FIGURES 1 and 2. This further simplifies the construction of the nozzle. It has

been found that the use of a converging section in a nozzle for use in gas-operated sonic generators is not necessary if a stabilizing section such as section 44 is used. It has been discovered that this is true whether the inside diameter of the pipe 48 supplying air to the generator is equal to or is greater than the diameter of stabilizing section 44.

The minimum value for the length K of stabilizing section 44 can be determined by the method outlined above for determining the minimum length of stabilizing section J of nozzle 10. In practice, the ratio of stabilizer section length K to diverging section length N is usually between 1/3 and 1/2. Nozzles using a ratio of K to N of 1/3 have proved especially desirable. Since the gas flowing in stabilizing section 44 has a Mach number of 1.0, the length N and divergence angle (d) of diverging section 46 can be determined in the same way that the corresponding values (b) and L of section 14 of nozzle 10 are determined. Similarly, the optimum values for the placement and depth dimensions Q and R of pulsator 40 can be determined in accordance with the principles set forth in my above-mentioned co-pending application.

The operating characteristics of three examples of nozzles built and operated in accordance with the embodiment of the invention shown in FIGURES 1 and 2 are given in the table below. The input air pressure and the output power of each of the units tested vary from relatively low values (4 p.s.i.g. and 400 watts) for the unit shown in Example 1, to relatively high values (30 p.s.i.g. and 1400 watts) for the unit shown in Example 3.

	Example 1	Example 2	Example 3
P ₀	4 p.s.i.g.....	8 p.s.i.g.....	30 p.s.i.g.....
Input air flow.....	12.87.....	15.62.....	30.76.....
T ₀	59° F.....	59° F.....	59° F.....
(a).....	30°.....	30°.....	30°.....
(b).....	15°.....	15°.....	15°.....
I.....	0.284 in.....	0.284 in.....	0.284 in.....
J.....	0.085 in.....	0.085 in.....	0.085 in.....
L.....	0.275.....	0.321.....	0.258.....
Y.....	0.245 in.....	0.200 in.....	0.245 in.....
Z.....	0.300 in.....	0.300 in.....	0.300 in.....
P _E	0.75 p.s.i.a.....	0.75 p.s.i.a.....	0.79 p.s.i.a.....
M _E	2.74.....	2.87.....	2.74.....
A _E	0.125 in. ²	0.141 in. ²	0.125 in. ²
Frequency of sonic output.....	6,000 c.p.s.....	6,000 c.p.s.....	6,000 c.p.s.....
Approx. sonic power output.....	400 watts.....	550 watts.....	1,400 watts.....

Where:

- P₀=input air pressure
Input air flow is given in cubic feet per minute
T₀=Input air temperature
(a)=nozzle angle of convergence
(b)=nozzle angle of divergence
I=length of converging nozzle section
J=length of cylindrical nozzle section
L=length of diverging nozzle section
Y=distance between nozzle exit and pulsator entrance
Z=pulsator depth
P_E=gas pressure at nozzle exit
M_E=gas Mach number at nozzle exit
A_E=nozzle area at nozzle exit

The frequency of the sonic output is given in cycles per second. The sonic power output was measured at the source.

Results similar to those given in the above table also have been obtained in tests of generators constructed in accordance with the embodiment of the invention shown in FIGURE 3 of the drawings.

Although specific preferred embodiments of the invention have been set forth in detail, it is desired to emphasize that these are not intended to be exhaustive or necessarily limitative; on the contrary, the showing herein is for the purpose of illustrating the invention and thus to enable others skilled in the art to adapt the invention in such ways as meet the requirements of particular ap-

plications, it being understood that various modifications may be made without departing from the scope of the invention.

I claim:

1. A gas-operated pressure wave generator, said generator comprising, in combination, a gas-accelerating nozzle comprising a body member forming a gas flow passageway, first, second and third longitudinal positions in said body member, said second position being spaced from said first position in the direction of flow of gas through said nozzle and said third position being spaced from said second position in the direction of flow of gas through said nozzle, restrictor means reducing the cross-sectional area of said gas flow passageway and forming a reduced orifice at said first longitudinal position, stabilizing means in said gas flow passageway between said reduced orifice and said second longitudinal position, said stabilizing means providing a substantially constant cross-sectional area for said passageway between said reduced orifice and said second longitudinal position, said stabilizing means also providing another orifice at said second longitudinal position, said other orifice having a cross-sectional area substantially equal to that of said reduced orifice, expansion means in said gas flow passageway between said other orifice and said third longitudinal position, said expansion means providing an increasing cross-sectional area for said passageway between said other orifice and said third longitudinal position in the direction of flow of gas through said nozzle, resonator means, and means for positioning said resonator means adjacent the exit opening of said gas flow passageway.

2. Apparatus as in claim 1 in which the passageway between said reduced orifice and said other orifice has a cylindrical shape.

3. Apparatus as in claim 1 in which the ratio of the cross-sectional area of said gas passageway at said third longitudinal position to the cross-sectional area of said gas passageway at said other orifice is at least 1.5.

4. A gas-operated pressure wave generator, said generator comprising, in combination, a gas-accelerating nozzle comprising a body member forming a gas flow passageway, first, second and third longitudinal positions in said body member, said second position being spaced from said first position in the direction of flow of gas through said nozzle and said third position being spaced from said second position in the direction of flow of gas through said nozzle, restrictor means reducing the cross-sectional area of said gas flow passageway and forming a reduced orifice at said first longitudinal position, stabilizing means between said reduced orifice and second longitudinal position providing a cylindrical shape for said gas flow, said stabilizing means also providing another orifice at said second longitudinal position, said other orifice having a cross-sectional area substantially equal to that of said reduced orifice, expansion means in said gas flow passageway between said other orifice and said third longitudinal position, said expansion means providing a frustro-conical shape for said passageway between said other orifice and said third longitudinal position in the direction of flow of gas through said nozzle, resonator means, and means for positioning said resonator means adjacent the exit opening of said gas flow passageway.

5. A gas-operated pressure wave generator, said generator comprising, in combination, a gas-accelerating nozzle comprising a body member forming a gas flow passageway, first, second and third longitudinal positions in said body member, said second position being spaced from said first position in the direction of flow of gas through said nozzle and said third position being spaced from said second position in the direction of flow of gas through said nozzle, restrictor means reducing the cross-sectional area of said gas flow passageway and forming a reduced orifice at said first longitudinal position, stabilizing means in said gas flow passageway between said reduced orifice and said second longitudinal position,

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said stabilizing means providing a substantially constant cross-sectional area for said passageway between said reduced orifice and said second longitudinal position, said stabilizing means also providing another orifice at said second longitudinal position, said other orifice having a cross-sectional area substantially equal to that of said reduced orifice, expansion means in said gas flow passageway between said other orifice and said third longitudinal position, said expansion means providing an increasing cross-sectional area for said passageway between said other orifice and said third longitudinal position in the direction of flow of gas through said nozzle, resonator means, and means for positioning said resonator means adjacent the exit opening of said gas flow passageway, said generator being adapted to be supplied with a compressed gas, to convert said compressed gas into a high-speed gas stream flowing in an ambient gaseous medium, and to generate pressure waves in said medium when the pressure of said compressed gas is less than the approximate value of P_0 given by the following equation when P equals the absolute pressure of said gaseous ambient medium and M is equal to 1.0:

$$\frac{P_0}{P} = \left[1 + \frac{k-1}{2} M^2 \right]^{\frac{k}{k-1}}$$

in which: P_0 is the absolute pressure of said compressed gas, and k is the ratio of specific heats for said compressed gas.

6. A gas-operated pressure wave generator, said generator comprising, in combination, a gas-accelerating nozzle comprising a body member forming a gas flow passageway, first, second and third longitudinal positions in said body member, said second position being spaced from said first position in the direction of flow of gas through said nozzle and said third position being spaced from said second position in the direction of flow of gas through said nozzle, restrictor means reducing the cross-sectional area of said gas flow passageway and forming a reduced orifice at said first longitudinal position, stabilizing means in said gas flow passageway between said reduced orifice and said second longitudinal position, said stabilizing means providing a substantially constant cross-sectional area for said passageway between said reduced orifice and said second longitudinal position, said stabilizing means also providing another orifice at said second longitudinal position, said other orifice having a cross-sectional area substantially equal to that of said reduced orifice, expansion means in said gas flow passageway between said other orifice and said third longitudinal position, said expansion means providing an increasing cross-sectional area for said passageway between said

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other orifice and said third longitudinal position in the direction of flow of gas through said nozzle, resonator means, and means for positioning said resonator means adjacent the exit opening of said gas flow passageway, said nozzle being adapted to produce and issue into a gaseous ambient medium a high-speed gas jet having oblique shock waves forming a periodic shock wave outline pattern, the first of said shock waves downstream from said exit opening of said gas passageway being a compressional shock wave, said resonator means having a reflecting surface located within said first shock wave.

7. A gas-operated sonic pressure wave generator comprising, in combination, a nozzle for producing a high-speed, low-pressure gas jet, said nozzle comprising a body having a conduit therethrough, said conduit including a converging frusto-conical shaped inlet section, a diverging frusto-conical shaped outlet section, and a cylindrical mid-section interconnecting the small ends of said inlet and outlet sections, a resonator member with a resonator cavity in it, and means for positioning said resonator member with said cavity facing the exit opening of said outlet section.

8. Apparatus as in claim 1 including a compressed gas supply tube, and in which said resonator means comprises a resonator cavity in said positioning means, said positioning means being adapted to engage and secure together said gas supply tube and said nozzle with said supply tube feeding compressed gas to said nozzle.

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