Economic Considerations in Industrial Ultrasonics

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Factors of importance in commercializing industrial ultrasonics.

SINCE the purpose of this series of articles is to present some rather simple theory of the action of ultrasonic energy, but with the main emphasis on the economic side, let us review what has been presented commercially so far.

It seems obvious that the key to exploitation of the art lies primarily in the generator. Impedance matching, transmission over a distance, and boundary layer problems are vital, but if there are no generators of a few hundred watts up to perhaps a thousand kilowatts, with long life and trouble-free operation over a period of months or years, the future is limited. Replacement of a simple part, such as a nozzle, can be considered practical if called for every few weeks or months.

Efficiency

Efficiency is also of great importance in many applications. This is not universal, because if we have a "jewelry" type load, such as a high-speed tool bit to make more dense, tough and uniform, we could afford to spend a kilowatt hour of power on it. We see this taking place in radio-frequency heating of metal parts, where due to the size and shape of the piece worked on, only a few per cent of the energy drawn from the line is actually effective in the piece itself.

In loads that run to high tonnage per day and possibly require a thousand kw or so, efficiencies of energy transfer into the load cannot be considered if they average only a few per cent, unless the product is extremely high-priced. The development cost of huge equipment is enormous, and if we must handle twenty kw to put one in the load, few industries will be able to consider using it.

In the higher power range, steam is a cheap source of energy, often running a half cent kw hour or less, and is often available in huge supply in existing plants. An oil refinery, for instance, has a great surplus of steam power available, which they obtain from the unusable lighter fractions that they would "flare off" (burn up) anyway. A steel mill usually has a few hundred hp excess capacity steam. And if steam is attractive due to its thermodynamical characteristics we need not be reminded an electrically fired steam boiler is 98% efficient.

If you decide on compressed air operation for large loads, a centrifugal turbine driven compressor is pretty efficient up to 40 pounds pressure. Since these are high rpm jobs, they go well with a turbo-jet ultrasonic generator that could be mounted on the same shaft, and it could operate up to 500 kw per rotor, if desired.

a device such as the turbojet generator already described, it needs some superheat. Wet steam has great erosive properties due to the velocity of the water particles in it traveling at considerable speed and impinging on a surface. In the rotor of the turbojet unit the velocities involved would cause the wet steam droplets to hit the moving parts with forces of the order of 40 tons to the square inch or higher, causing considerable rotor wear in a short time. So a hundred degrees of superheat would be necessary.

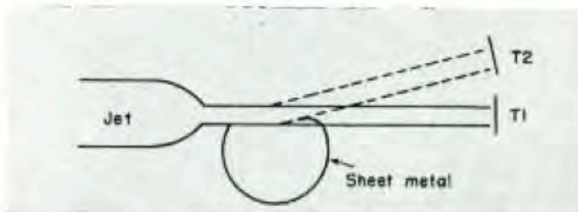

Fig. 1. A simple method of designing a self-modulated jet. See text.

There is one range of powers that we have considered only briefly—from perhaps 50 watts to a kilowatt. It seems reasonable that if ultrasonics is ever in general use in large numbers of units, it must enter the home or shop in small units of this power requirement. A shining example is the home laundry application, etc.

Power Source

We must keep in mind that even though our ultrasonic device were 100% efficient, and cost nothing to produce, it must still have a source of power suitable to it. If we need a few kw of compressed air, and there is no air supply on the premises, a compressor is noisy, expensive, and not too efficient. A small steam boiler can also be quite a nuisance, especially the boiler feed water and safety angles. A water pump is cheap and efficient and fairly quiet if the proper type is chosen. If we consider something in the way of a electro-acoustical transducer, such as magnetostriction or quartz, we have the expense of a high-power electronic oscillator.

Steam is also subject to another difficulty. If you intend to use it in

The sources of power readily available in most locations are 110 or 220 volts, 60 cycles. We often have a water tap available that will deliver 10 to 20 cubic inches a second at a pressure of 40 pounds or so, representing a power of 50 to 100 watts. Many places also have gas for heating.

For widespread use of a few hundred watts of ultrasonic energy, then, we must work with these limitations. The ideal generator would be a crystal transducer of a few ohms impedance which we could hook directly across the 110-volt line and have the 60 cycles shock excite it into continuous oscillations at say 25 kc or so. Unfortunately, mother nature has not provided us with such a device, and there seems little likelihood of it ever being discovered.

Use of the water supply seems distinctly hopeful. It already contains say 50 watts of energy as it comes from the tap in most places. The main problem then is to modulate it into discrete bullets or slugs separated by twice their length, as shown previously.[1]

Any self-resonant oscillator using a fluid medium, such as an organ pipe of whistle, seems to have an inherent efficiency of about 3 or 4 per cent.

Expressed another way, the percentage modulation seems to be limited to that figure. Even the Hartmann generator, which operates with what might be termed "solid air"—that is, air moving at sonic velocity and consequently obeying a different set of rules than the normal ones—has the same limitation.

This problem must be overcome. We cannot build a useful art on 4% efficiency, and the jet or whistle principle is too simple and obvious to be overlooked in our search for the ideal small generator. If we reach high efficiencies with water in the jet, we shall probably have terrific impact values from our deliberate high values of what is almost equivalent to turbulence. This we can hope to overcome two ways—first by using erosion-resisting materials such as carboloy and, second, when we understand the laws of fluid flow better in the special case of small jets of this nature, we can arrange to have the water impact fall on a fluid instead of on the solid material forming the jet.

This last thought needs a little elaboration. Observation teaches us the ocean can wear away the shore, but the shore cannot wear away the ocean. A fluid at high velocity can erode almost any solid in time, but remains unaffected itself. On the other hand, a fluid impacting on a fluid may develop any value of shock impact pressure up to infinity and not "wear out." Of course, it may turn into steam, or suffer chemical changes which may be highly desirable or the reverse, but it is certainly not subject to erosion.

This thought allows us to hope that intelligent design will provide a fluid cushion to absorb high power density without harm, and also act as a power distributor to take the high *unit* powers and spread them over a larger area, so that we have the same power, but at lower unit values.

In this discussion we shall use the term "air" for any highly compressible fluid, and "water" for a relatively uncompressible fluid. In general, the compressible fluid has much less density than the uncompressible one—in round numbers, about one-thousandth as much, for instance, so its mass can be neglected. We could also work with hydrogen and mercury, for an extreme case.

Self-Modulated Jet

In our search for a 100% self-modulated jet, the arrangement shown in *Fig. 1* is of interest. It is well known that a well formed jet of water from a well designed nozzle at proper pressure will maintain its uniform cross-section for some distance—at least for an inch or so. So we arrange to have the jet impinge on target No. 1 directly in its path, to which it will give a steady d-c push, which does not interest us. If we take a thin strip of metal and form a deflector as shown and insert it partly into the stream, it will pick up a portion of the water, bring it around in a smooth curve, and strike the stream near the nozzle. This should give a right angle component that will deflect the main stream to target No. 2. The deflection must be sufficient so that the stream no longer hits the deflector, thus stopping the stream around the deflector and removing the right angle component so the stream returns to its original position, and the process is repeated. Since the stream alternates between the two targets, a.c. is produced.

The writer has not tried this out, giving it as an example of the kind of thinking that must be done on jets in general. There is a nice phasing and amplitude problem in this arrangement, but we have the mechanical stepup of the angle of deflection of the jet, which can be theoretically very large. It has the great advantage of simplicity, but we should be able to try it out with water pressure from the faucet and obtain medium audio frequencies out of it. A proper nozzle will give you nearly 50 feet a second velocity from the kitchen faucet. This should also be tried with compressed air.

A more important type of interrupter jet is shown in several forms in *Fig. 2*. Here we arrange to introduce air in disciplined bubble form in a stream of water. We always start with a water jet of more or less conventional design, which performs the usual function of converting the static head pressure of the water to velocity head, having kinetic energy.

Concentrically mounted inside the water jet (WJ) we have a critically adjustable air jet (AJ). At this point it begins vaguely to resemble our old friend, the aspirator. If operated this way, with no detail to give an a-c component to our air or water pressure or velocity, it would simply mix the two in the usual aspirator fashion. To remind you of your high school physics, the water jet so completely changes the static head to kinetic or velocity, that there is no pressure at all left, so the pressure in the throat of a venturi is practically zero absolute. The air outside is still at 14.7 pounds absolute, so it is forced into the aspirator and mixed in random manner with the water. Again to remind you, you can easily obtain 26 inches of vacuum this way.

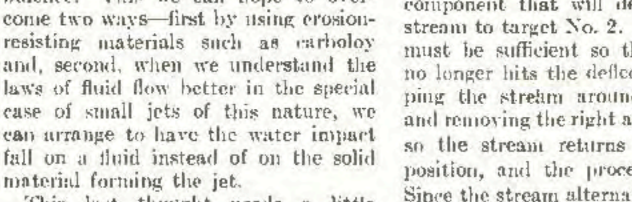

Fig. 2. Interrupter jet. The position of the air injection point in (a) is critical. In (b), the insertion point is not so critical.

Jet Size

What diameter shall we make the jet? Since our object is to generate a.c. by "pushing" in one direction only when our water slugs hit a target, we can effectively push only one third of a cycle, allowing the elasticity of the load to carry on for the complete cycle. Therefore our water slugs must be separated by twice their length.

If we set up a trial case of one inch diameter and with cylindrical slugs one inch long, each complete cycle is represented by one slug with two air slugs for spacers. The assembly would be three inches long, and if we wanted 24,000 per second, our velocity would be 72,000 inches/sec, or 6,000 feet a second, which is pretty high, although possibly attainable.

If we go to one-tenth inch diameter our necessary velocity comes down to 600 ft/second, and so on. So we calculate about .050 inches (50 mils) is a nice size for experiment, with 300 ft/sec and a power of about 67 watts or so. We must start with an initial velocity of the water of about 100 ft/sec. which requires about 125 pounds pressure through a good orifice.

For initial experiment, though, we could design for say 5,000-cycle operation, and then the initial water pressure can be usually obtained from a faucet. Also the air compressor requirement can be met by the usual small compressor we often have in a shop.

The theory of such small jets and pipes is not very well understood. You are operating at such high Reynold's numbers that you are off the tables completely. It is necessary that internal parts be well contoured and smooth to minimize turbulence.

In *Fig. 2A* the position of the air injection is bound to be very critical as in the length of the water jet proper there is a complete conversion from pressure to velocity. In *Fig. 2B* however, this is obviously not so serious, as it is pure velocity at the insertion point.

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The air must be inserted in a pulse manner, so that the water slugs will have as well defined length limits as possible. This can possibly be accomplished by having both columns of fluid resonate as shown.

If we feed the inner concentric air jet with the turbojet unit, as shown previously,[1] then we have ideal conditions, as the slug of air can be adjusted to have more than sonic velocity, with an extremely sharp leading edge, and very large peak pressures.

[1] S. Young, "Ultrasonics in Solids," Oct., 191.