

An inexpensive vibrating orifice monodisperse droplet generator using a hard drive actuator arm

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We propose that the voice coil actuators found in magnetic hard drives are fit to supercede loudspeakers as vibration sources in the laboratory setting. A specific use case is the excitation of a liquid jet to induce controlled breakup into monodisperse droplets. Like speakers, hard drive actuators are cheap and ubiquitous, but they are less unwieldy and offer greater amplitudes without producing noise. No machining tools or amplifying electronics are needed for the construction and operation of the presented droplet generator.

I. INTRODUCTION

The calibration of spray characterization instruments requires a source of monodisperse droplets. Although drop-on-demand approaches promise precise control over the droplet generation, their everyday operation poses challenges (aspired air bubbles, liquid pileups, satellite droplets, etc.). Consequently, researchers often fall back on continuous-stream drop generators whenever the droplets' exact timing is less important.

Most continuous-stream drop generators are based on the breakup of a liquid jet into equally-sized, even-spaced droplets when excited with oscillations of an appropriate frequency. This simple principle has been employed for fifty years, with orifices typically attached to either one of two vibrating mechanisms: an ordinary loudspeaker, first employed by Donnelly and Glaberson¹, or a piezoelectric element, as first proposed by Schneider and Hendricks² and popularized by Berglund and Liu's design³.

In this paper, we propose a source of oscillation as inexpensive and ubiquitous as a speaker and as convenient as a piezoelectric element: the actuator arm found in every magnetic hard drive.



FIG. 1. The fully assembled droplet generator. Nozzle is shown as inserted through actuator arm.

II. CHARACTERISTICS

With high-capacity and solid-state devices rapidly pushing older hard drives into obsolescence, it should be a simple matter to acquire a few specimens for demolition. Hard drives come in two form factors—3.5 and 2.5 inches wide, respectively—and both can be used for the purposes of this paper.

Unlike loudspeakers, hard drives have a flat base plate which can be drilled into, allowing for easy installation on any experiment jig. Save for a drill and a saw, no machining tools are needed for the construction of the droplet generator.

Like piezoelectric elements, vibrating actuator arms are very quiet, enabling use at frequencies and amplitudes that would far exceed responsible levels on a speaker. In our experiments, the actuator responded to frequencies throughout our hearing range—i.e., up to 17 kHz—and likely well beyond, though we have not tested the full response range for any given amplitude.

As an added advantage over other designs, no amplification is needed. Below 100 Hz, amplitudes on the order of 0.5 cm are easily achieved (albeit they are of course not needed for droplet production) when a peak-to-peak voltage of 2–4 V is applied. The movement scales down with the inverse of the frequency, however, such that amplitudes are much smaller at typical operating frequencies (0.5 – 10 kHz). Nevertheless, the voltages required are well within the ability of any standard laboratory function generator, and can likely even be produced by many consumer-level computer sound cards.

Finally, glass needle orifices fabricated for use with existing loudspeaker setups can be reused, and are easily produced by hand from heated borosilicate capillaries or using a micropipette puller. The process is illustrated in FIG. 2 and in-depth instructions are given by Lee⁴. Piezoelectric-based devices, on the other hand, need fitted orifices to produce a range of drop sizes.

III. CONSTRUCTION

Forgo multi-platter drives, as they are cumbersome to disassemble and have bulky, complex actuator assemblies. The device shown in FIG. 1 is based on a single-platter drive.

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FIG. 2. Above: assembly of nozzle from low-gauge hypodermic syringe (Luer fitting) and capillary. Below: nozzle tip fabrication, capillary from left to right: broken, sanded, heated in a flame (I.D. 200 μm), heated for longer (I.D. 25 μm , could be sanded down by about 200 μm), overheated (I.D. 0 μm).

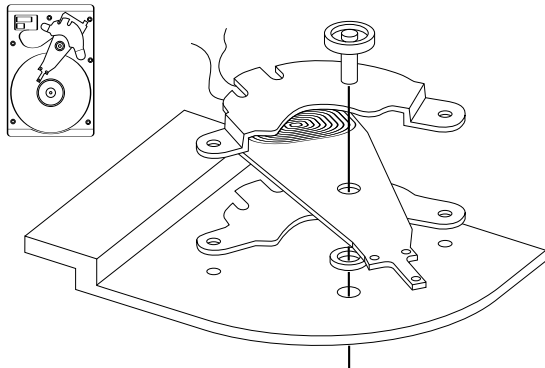


FIG. 3. Top view of a hard drive and exploded view of the cut-out base plate, actuator arm, axis, and magnet assembly.

a. Dismantle and cut. After removing the hard drive cover, remove the magnet holder, arm axis, arm, ribbon wires, circuit boards, and platters such that only the base plate remains. Now the corner of the base plate holding the actuator arm assembly can be cut out to yield the result shown in FIG. 3. A band saw, jigsaw or powered hacksaw will be very useful, although not necessary.

b. Expose coil leads. Next, remove the read/write head and all circuitry leading to it. It can be difficult to discriminate between wiring connected to the drive's I/O electronics and the two strands powering the voice coil—we are interested only in the latter, and must be careful not to damage them. Finally, replace the actuator arm, axis and magnet assembly.

c. Add protective cover. We recommend bolting on a cover plate, such as a small sheet of acrylic or polycarbonate, to protect the protruding arm from acciden-

tal bending. Drill a hole through the cover to allow the nozzle to be threaded through the arm. A severable connection from coil to function generator is preferable to a direct wire, if only because the voice coil leads are delicate and easily torn off. To this end, we epoxied an audio jack into the cover and soldered the voice coil leads to it from the bottom.

IV. OPERATION

How the nozzle can be held in place falls beyond the scope of this article; we note that the interchangeability of nozzles with Luer fittings has proved very convenient in our application. The nozzle must be connected to an accurately calibrated syringe pump. If a water supply line is integrated into the setup via a T-valve between pump and nozzle, ensure that it is shut closed before operation since pressure fluctuations at the nozzle are the most common culprit for unstable droplet generation.

As with other vibrating orifice droplet generators, it is crucial that stable conditions are established before any experiments can begin. First, ensure that the liquid is ejected in a single jet. Multiple jets can be due to a clogged orifice (a mixture of distilled water and CLR®, drawn back through a syringe, is an excellent remedy). Satellite droplets can also form secondary jets, in which case the oscillation frequency must be adjusted or the amplitude reduced. Satellite formation is easily detected by using a gentle air flow to deflect the jet—if the droplets are truly monodisperse, they will all deflect at the same angle.⁵

Note also that the orifice diameter D_o dictates that the range of viable frequencies f as $3.5 \lesssim \frac{Q}{\pi f (\frac{D_o}{2})^2} \lesssim 7$, where Q is the flow rate).^{6,7} In practice, D_o need not be precisely determined; it is easy to find appropriate settings for Q and f by viewing the jet against a strobe light, adjusting flow rate for a breakup length on the order of $10D_o$ (empirically for water), then tuning the frequency until droplets appear evenly spaced and spherical.

Under stable conditions, every oscillation of the nozzle will produce one droplet downstream,⁷ such that the droplet diameter will be $D_d = \sqrt[3]{6Q/(\pi f)}$.

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