# A simple vibrating orifice monodisperse droplet generator using a hard drive actuator arm

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We propose that the rotary voice coil actuators found in magnetic hard drives are fit to supercede loudspeakers as expedient 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 loudspeakers, which are typically used for prototyping such devices, hard drive actuators are cheap and ubiquitous, but they are less unwieldy and supply greater amplitudes without producing noise. Frequencies between 0 and 17 kHz, and likely beyond, can be reproduced reliably. No machining tools or amplifying electronics are needed for the construction and operation of the presented droplet generator.

## I. INTRODUCTION

Sources of monodisperse droplets are needed in a wide range of research applications from droplet-wall collision experiments[1] to aerosol studies[2]. Our particular case was the calibration of optical spray characterization instruments (Phase-Doppler Anemometry and Interferometric Particle Imaging).

Although drop-on-demand approaches (e.g. via pressure pulses, microfluidic devices etc.) promise precise control over the droplet generation, their everyday operation poses challenges (aspired air bubbles, liquid pile-ups, satellite droplets, etc.). Consequently, researchers often fall back on relatively hassle-free continous-stream drop generators whenever the droplets' exact timing is less important.

Continuous-stream drop generators are based on *Rayleigh breakup*, i.e. the disintegration of a disturbed liquid jet into droplets. The physics behind this phenomenon have been studied for almost two centuries[3,4] and are well-understood. When the jet disturbances are induced by carefully controlled mechanical vibrations at an appropriate frequency, the droplets will be of uniform size and evenly spaced.

This simple principle has been employed to generate droplets for fifty years, with orifices typically attached to either one of two vibrating mechanisms: an ordinary loudspeaker, first used by Donnelly and Glaberson[5], or a piezoelectric element, as first proposed by Schneider and Hendricks[6] and popularized by Berglund and Liu's design[7].

Both approaches have drawbacks: by design, a speaker vibrating at a fixed pitch produces an audible sound, jeopardizing the laboratory peace. Speakers are unshapely, difficult to fasten onto an experimental setup and their cones provide no robust structure to which any type of orifice could be attached. Piezoelectric elements cost more and are useful only when integrated with the orifice—precision machined droplet generators operating this way are commercially available, but unreasonably expensive for early-stage projects. As a result, we felt compelled to consider alternative sources of vibration that require a minimum effort to build and install using standard lab equipment.

FIG. 1. 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 $\mu$m), heated for longer (I.D. 25 $\mu$m, could be sanded down by about 200 $\mu$m), overheated (I.D. 0 $\mu$m).

We propose that the actuator mechanism found in every magnetic hard drive is an optimal low-budget candidate for precision oscillation needs:

*Very low cost.* With high-capacity and solid-state devices rapidly pushing older hard drives into obsolescence, it should be a simple matter to acquire a few decommissioned 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.

Further, 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. 1 and in-depth instructions are given by Lee[8]. Piezoelectric-based devices, on the other hand, need fitted orifices to produce a range of drop sizes.

*Ease of construction and installation.* 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.

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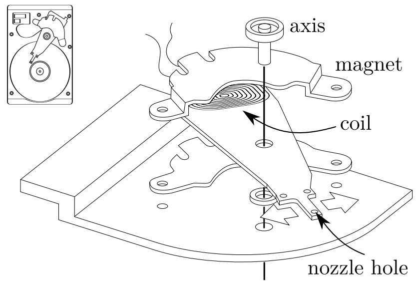


FIG. 2. Top view of a hard drive and exploded view of the cut-out base plate, actuator arm, axis, and magnet assembly.

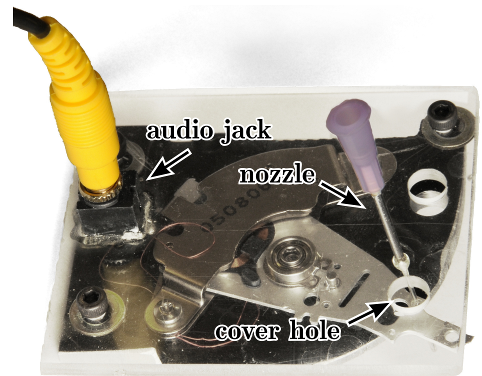


FIG. 3. A fully assembled droplet generator from a single-platter drive. Nozzle is shown as inserted through one of the holes in the actuator arm.

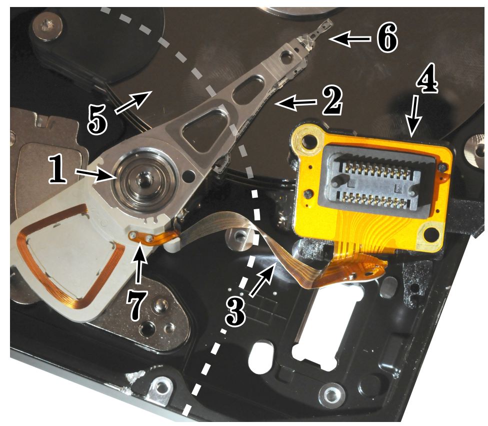


FIG. 4. A multi-platter hard drive after removing cover and detaching circuit board (4). Top magnet is removed. Base plate can be cut along dashed line.

*High amplitudes without noise.* Like piezoelectric elements, vibrating actuator arms are very quiet, enabling use at frequencies and amplitudes that 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.

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 amplitude scales down with the inverse of the frequency, however, such that they 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; they can likely even be produced by many consumer-level computer sound cards.

## II. OPERATING PRINCIPLE

Magnetic hard drives store data as sub-micron-sized patterns of oppositely magnetized dots on disks called *platters*. The read-write head is mounted at the tip of an arm that pivots across the platter surface while the platter spins. This setup allows the head to access the entire platter surface.

FIG. 2 illustrates schematically the design of a typical rotary actuator arm assembly. The flat voice coil mounted on the surface is responsible for the arm's side-to-side movement: as it is positioned under a permanent magnet, the coil creates a sideward force (*Lorenz* or *Laplace* force) when a current flows through its wires. The force is aligned with the cross product of the current direction and the magnetic field lines. By stopping or reversing the current, the arm's motion is likewise stopped or reversed. An applied sinusoid signal can thus be used to make the arm oscillate laterally at the desired frequency.

## III. CONSTRUCTION

If possible, forgo multi-platter drives, as they are more cumbersome to disassemble and have bulky, complex actuator assemblies. The device shown in FIG. 3 is based on a single-platter drive.

*a. Dismantle and cut.* After removing the hard drive cover, remove the top magnet, arm axis (1 in FIG. 4), arm (2), ribbon wires (3), circuit boards (4), and platters (5) such that only the base plate remains. Now the corner of the base plate holding the actuator arm assembly can be cut out (dashed line) to yield a shape as shown in FIG. 2. A band saw, jigsaw or powered hacksaw will be very useful, although not necessary. The goal is to allow the tip of the arm to protrude over the edge. After cutting, reinstall the arm, axis, and top magnet.

*b. Expose coil leads.* Next, remove the read/write head (6) and all wiring leading to it, along with any connected I/O and servo circuitry (4). Be careful, however, not to tear off the two strands powering the voice coil, which are often integrated in the same ribbon cable (3).

If you wish to remove the latter, ensure that exposed terminals (7) remain onto which you can solder new leads.

*c. Add protective cover.* We recommend bolting on a cover plate, such as a small sheet of transparent plastic, to protect the protruding arm from accidental 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 plate (see FIG. 3) and soldered the voice coil leads to it from the bottom.

## IV. OPERATION

To use the droplet generator, simply insert a nozzle through a small hole at the tip of the actuator arm—typically at least one hole will already be present where the read/write head was installed—and connect the voice coil leads to the output terminal of a function generator set to an initial peak-to-peak voltage of 1 V and a sinusoid frequency of about 50 Hz, which should cause weak but perceptible oscillations.

Interchangeable nozzles made from needles with Luer fittings, as in FIG. 1, are convenient and can be held in place by a male adapter clamped into a lab stand.

The nozzle must be supplied by an accurately calibrated syringe pump. It is convenient to integrate a large liquid reservoir (or tap water hose) via a T-valve between the between pump and nozzle to permit quick topping up of the syringe. In such a setup ensure that the reservoir valve is shut closed before operation, since pressure fluctuations at the nozzle are the most common culprit for unstable jet breakup conditions.

As with other vibrating orifice droplet generators, it is crucial that stable conditions are established before any experiments can begin. First, confirm 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.[9]

Note also that the orifice diameter $D_o$ dictates the range of viable frequencies $f$ as

$$3.5 \lesssim \frac{Q}{\pi f \left(\frac{D_o}{2}\right)^2} \lesssim 7, \tag{1}$$

where $Q$ is the flow rate.[3,4] 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. It can be helpful to mount a magnifying lens in front of the orifice, as the adjustment procedure can become tedious when the droplets are very small.

Under stable conditions, every oscillation of the nozzle will produce one droplet downstream,[4] such that the droplet diameter will be

$$D_d = \sqrt[3]{6Q/(\pi f)}. \tag{2}$$

This can be verified photographically, as shown in FIG. 5.

We have successfully used the generator to produce droplets of $0.1 - 1\,\mathrm{mm}$ diameter, but both smaller and larger droplets are feasible.

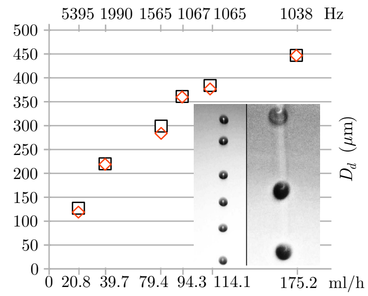


FIG. 5. Some frequency/flow rate conditions under which stable droplets were produced (□ as predicted by Eq. 2, ◇ as estimated from photographs). Photos shown are $D_d = 200\,\mu\mathrm{m}$ and $D_d = 386\,\mu\mathrm{m}$, respectively.

## V. CONCLUSION

We have successfully utilized the actuator assembly of a standard magnetic hard drive as a vibration source in a monodisperse droplet generator. The droplet generator is not only inexpensive, but remarkably easy to build and painless in its operation—particularly in comparison to loudspeakers or piezoelectric elements. These characteristics make hard drive actuators an excellent source of vibration, likely not only in the context of droplet generation but also for other purposes in the laboratory or classroom setting.


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