# 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

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 spray characterization instruments (Phase-Doppler Anemometry and Interferometric Particle Imaging).

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 continous-stream drop generators whenever the droplets' exact timing is less important.

Most 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 disturbances are induced by carefully controlled mechanical vibration at an appropriate frequency, the droplets will be of uniform size and evenly spaced.

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 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. It is unshapely, difficult to fasten onto an experimental setup and its cone provides 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 in many situations. 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. We propose that the actuator mechanism found in every magnetic hard drive is an optimal low-budget candidate for precision oscillation needs:

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

*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 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. 2 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.

*High amplitudes without noise.* 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 amplitude 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 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. 3 illustrates schematically the design of a typical actuator arm assembly. The flat voice coil mounted on the surface is responsible for the side-to-side movement: as it is positioned under a permanent magnet, the coil creates a sideward force when a current flows through its wires. By stopping or reversing the current the arm's motion is likewise stopped or reversed. Since a typical hard drive's platter spins at up to 7200 RPM, actuator arms must be able to move with extreme speed and precision. They are thus engineered to be very light yet stiff. These characteristics make a magnetic hard drive's actuator arm an ideal supplier of in-plane vibrations. Indeed, hard drive actuators are remarkable not for their operating principle but for their low cost; it is only the economics of mass manufacturing that have in recent years enabled these high-speed, lightweight mechanisms to become widely available.

## 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. 1 is based on a single-platter drive.

*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.

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

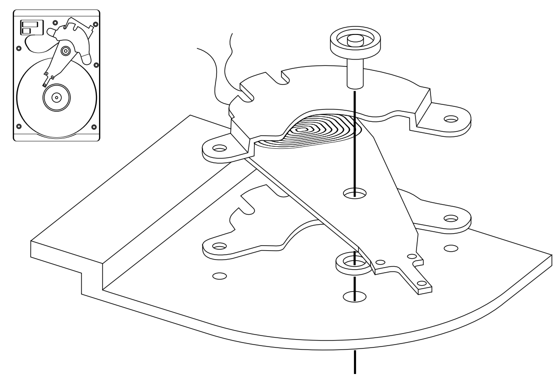

FIG. 3. Top view of a hard drive and exploded view of the cut-out base plate, actuator arm, axis, and magnet assembly.

*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 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 and soldered the voice coil leads to it from the bottom.

## IV. OPERATION

We used existing nozzles manufactured by hand from hypodermic needle stubs and heated glass capillaries (FIG. 2). We make no claim that this is the best ap-

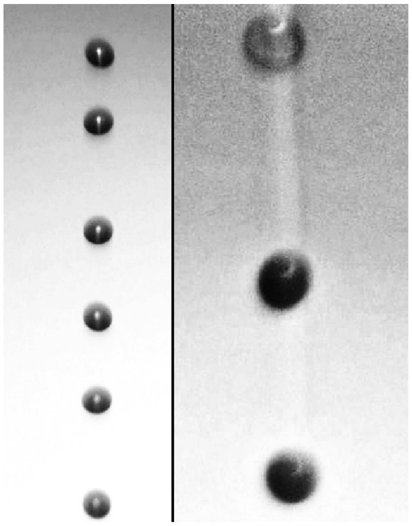

FIG. 4. Photographs of different droplet sizes ($226\,\mu$m and $386\,\mu$m) produced with the droplet generator shown in FIG. 1. Scales have been cropped out.

proach to take, but we note that the interchangeability of nozzles with Luer fittings has proved very convenient in our application. How the nozzle can be held in place falls beyond the scope of this article; while we used an existing jig from machined aluminum, a small lab stand and clamp should suffice.

The nozzle must be connected to an accurately calibrated syringe pump. It is convenient to integrate a water supply line into the setup via a T-valve between pump and nozzle. In this case, ensure that the 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, 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.[9]

Note also that the orifice diameter $D_o$ dictates the range of viable frequencies $f$ as $3.5 \lesssim \frac{Q}{\pi f\left(\frac{D_o}{2}\right)^2} \lesssim 7$, 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 as the droplets become very small.

Under stable conditions, every oscillation of the nozzle will produce one droplet downstream,[4] such that the droplet diameter will be $D_d = \sqrt[3]{6Q/(\pi f)}$. This can be verified photographically, as shown in FIG. 4.

## V. CONCLUSION

This is a great droplet generator, because ...


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