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Reviving Blacksmithing with an Open Die Forging Hammer

Will B. Doerting

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Faculty Mentor: James Wade

With grant funding from the University of Kentucky Office of Undergraduate Research, the goal of constructing an open die forging hammer (typically called a power hammer) for the UK Metal Arts facility was a success. The project would not have been possible without the cooperation of the sculpture faculty and the resources provided by the grant award. The execution of the project proved to be time consuming and challenging, but an overall rewarding experience.

The goals outlined by the initial proposal were designed to address multiple shortfalls within the sculpture department. One aspect relates to insufficient departmental funding to purchase the necessary machinery for certain operations, including a power hammer. The success of this objective is clearly defined, because there is now a power hammer available in the Metal Arts facility.

The second goal is more abstract, seeking to change a larger cultural trend within the sculpture community. There are few students who develop enough interest in blacksmithing to put forth the necessary time to learn all of the skills required to master the traditional process. This is in part related to the amount of time and physical effort involved with the arduous parts of the process which involves roughing out forms with hours of hammer blows by hand. By the time the general shape is reached, most students are exhausted and bored from the repetitive action. This leaves little interest in the finite skills needed to turn a piece from pounded steel into a spectacular piece of craft. Providing a power hammer for the students allows the boring parts of the process to be completed in a short period of time with much less physical effort, leaving the time and energy to learn more about a nearly forgotten skill set.

Power hammers have been used in commercial production since the industrial revolution. They range in size (measured in weight of the striking ram) from a few pounds to hundreds of tons. For a sculpture facility, a massive commercial hammer would be unnecessary and provide hammer blows which would be too powerful for most applications. There are smaller hammers which are manufactured for artist blacksmiths, but to get one that has a ram weight over 100 pounds costs an average of $9,000 to $12,000. Most professional and hobby blacksmiths find themselves working within a limited budget, leading to the development of alternative machines designed and constructed by the individuals who need them.

Though other power hammers have been constructed by individual blacksmiths, most lack the flexibility to serve numerous functions, cannot be moved from one shop to another, or are simply too small to complete most tasks. These two requirements multiplied the labor hours and necessary material, but were important innovations to make the machine practical for sculpture students. A 150 pound ram weight is necessary to provide enough power to work with steel that is up to four inches thick, but is not too powerful to work with stock that is ½ inch thick. The machine was the only one of its kind that could be found via an internet search – the largest ever built by an individual and the only one that can be disassembled and moved by hand. All of the other documented power hammers built by individuals are smaller, which limits their utility for large-scale work.
The modular construction is the major distinguishing feature of the machine. Usually, large power hammers are constructed in the place where they will ultimately be in operation, because once the pile of heavy parts is welded together, moving the machine can be impossible without a forklift or gantry crane in conjunction with a commercial trailer or flatbed truck. Single piece construction limits the project to those who have an established location for their shop and don’t have to worry about relocation. Art students do not have that luxury as most will move for careers or graduate programs. If fully disassembled, each component in the machine weighs less than 200 pounds, allowing it to be moved by two artists and a pickup truck. This also allows the machine to be set up in a location which would be inaccessible to moving equipment, like a basement studio.

The modular construction method has the disadvantage of taking several times longer than welding all of the components together because the alignment and production of bolt holes are much more time consuming. The assembly that guides the moving ram required drilling 5/8 inch holes though a total of three feet of steel (see figure 4). More structural components are necessary in order to maintain the same amount of rigidity that would result from welded connections. By the time the machine was complete, more than 600 components were measured, cut, positioned, and bolted into place (see figures 1-3).

Execution of the project began with the collection of necessary steel stock, parts like bearings and pulleys from commercial suppliers, a large electric motor, and necessary tools including blow torch tips and drill bits. The time spent fabricating the machine added up to roughly 700-1000 hours, not including time spent on careful calculation and design solution. All of the individual components were based on preliminary designs, but due to the complexity of the mechanisms, every part was designed to fit previous components, while planning for later additions. This helped create a relatively compact machine in which all of the moving parts could be contained within a safety cage if the machine were ever placed in the middle of shop where the back would be accessible.

The main drive mechanisms are built around a 5 horsepower electric motor which operates at 1750 rpm. If the motor’s speed were to be transferred directly to the moving ram, even the slightest amount of pressure applied to the throttle pedal would produce an unmanageably high strike rate. This necessitated the reduction in speed through a series of pulleys driven by rubber V-belts. The motor transmits its power through one of the belts to the bottom drive shaft which continuously runs a 90 pound flywheel as long as the power is turned on to the machine. This flywheel provides the inertia to move the secondary drive shaft, which translates the rotational movement to linear movement via an offset driveshaft. As the driveshaft turns, it pushes an adjustable driveshaft connected to laminated sections of 5160 spring steel plate positioned on a rocker arm. As this spring moves up and down, the ram moves with it, providing the necessary action to forge hot steel between the hardened dies.

In order for the movement of all the components to continue uninterrupted, the weight of the striking ram must be matched with an appropriately sized lower anvil, which provides the mass needed to deflect the ram and push it upward using the kinetic energy within the spring steel at the top of the ram. Most commercial machines use an anvil which weighs at least 8 to 10 times
the total weight of the striking ram, so a typical 100 pound hammer would have a half ton block of steel or iron beneath the lower tooling die. A solid block of steel would contradict the emphasis on the mobility of the power hammer, so instead, a hollow box made of plate steel was constructed and filled with silica sand. The sand serves the purpose of providing the weight to rebound the striking ram while helping to dampen the intense noise and vibration from the striking action. The problem with loose sand is that it eventually pulverizes and turns to fine dust which would work its way out from under the lid on top of the box. In order to solve this problem, the sand was mixed with bentonite (a raw ingredient in most pottery clays) and machine oil. The two ingredients allow the sand to stick to itself and be compacted tightly in the container (see figure 5).

The hardened dies are the most crucial element in the utility of the power hammer because they are in contact with the hot metal and determine what shapes can be produced. For example, rounded dies with a steep slope can rapidly stretch metal out, but produce deep gouges in the metal which must be smoothed out. Dies that are more flattened produce a smoother texture, but require more time to stretch or shape material. If a custom shape is needed, the dies can be altered to create it. For example, turning round stock into a hexagon can be accomplished by grinding three negative facets into the top and bottom dies. The dies for the machine can be shaped out of cold rolled steel and heat treated with a small electric kiln in conjunction with an alkaline quench bath (see figure 6). The completed dies are quickly interchangeable using integrated set screws located on the striking ram and bottom anvil. This allows for a limitless number of custom dies to be made without the aid of a machine shop or the need to purchase them from a manufacturer.

Most of the fabrication for the power hammer was straightforward and came together piece by piece. When the time came for an initial test run, all of the mechanisms performed as expected. However, after a few minutes of forging three inch diameter round steel, a series of welds on the top rocker arm broke from metal fatigue, causing the spring steel plates to break free of the machine (see figure 7). All of the machine’s components were designed to handle a large amount of torque and mechanical stress, but vibrations and sudden direction changes within the mechanism threatened to tear the mechanisms apart. The damage which resulted from the trial run and the fear of future components failures led to the reconstruction of more than half of the drive mechanisms. Construction that was previously imagined to be overkill was reinforced or replaced by stronger and thicker steel (see figures 8-9).

After numerous hours of reconstruction, the replacement parts functioned without any signs of failure. The design changes did add weight to the machine, a drawback which could certainly be justified with the resulting safety improvements.

Today, the functioning power hammer weighs over 4,000 pounds, is over 9 feet tall, and can strike the 150 pound ram down three times per second. The project was beyond comprehension for most right brained art students, who quickly grew tired of my attempts to explain the engineering hurdles and numerous calculations involved in the fabrication process. The power hammer also received acclaim from the majority of the UK police officers, who discovered that I would always be in the shop at 4 am with a fresh pot of coffee.
The machine will continue to be the subject of changes and improvements as new innovations result from its use. Despite the volume of time and mental exhaustion that resulted from the project, I would not hesitate to do it again.
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Figure 1
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Figure 3
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Figure 6
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Figure 8