The Mill at Anselma

Technical Guide

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Contents

Introduction

The first document written to describe the technical operation of our mill was entitled "Technical Information", written in 2004 and updated in 2006. This document focused on the millstones, the millstone furniture, and the mill machinery. It described their operation, and standardized the nomenclature of all of the related parts in our colonial era mill. All of this information has been recently updated and incorporated in this document.

Since 2005, a journal has been kept in which all of the data for each production grind has been recorded. The journal also documents repairs made, problems encountered, and their resolution. Beginning in 2008, additional data was recorded pertaining to pond level drop during production grinds and the duration of each grind. We now have five years of this data which is very useful in determining peak water usage during production grinds. Knowing the peak water flow to the water wheel, the power and torque generated by the water wheel can be determined. Power calculations are relatively straight forward, but torque calculations are not. There doesn't seem to be any uniform treatment of water wheel torque in the literature. Some derivations are difficult to follow, and some appear to be in error. For this reason, the torque expressions are developed from first principles in this document.

No attempt has been made to factor in water wheel or machinery efficiencies, or variations in water wheel R_{pm}, or the precise radius of the water wheel buckets, etc. As a result, the calculations in this document are probably accurate to within ten per cent.

Water Source and Water Flow

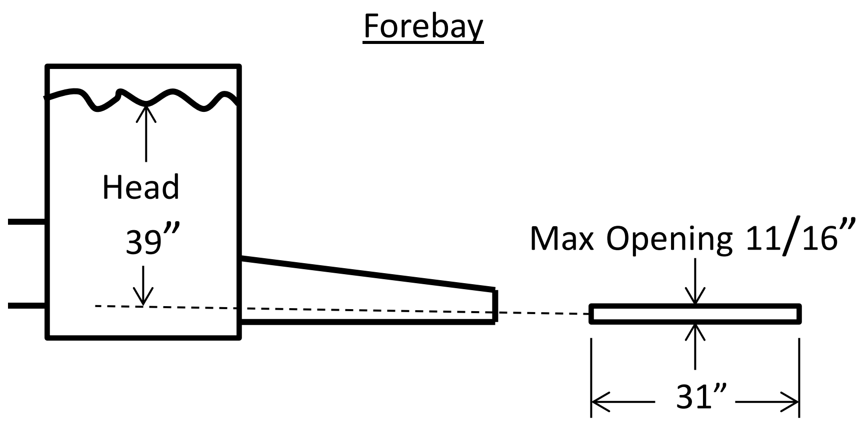
The mill pond surface area is 32,000 square feet (see appendix A), or approximately three quarters of an acre. Its maximum depth is 2.9 feet[1]. Originally, the source of water for the mill pond was the Pickering Creek. A race carried the water from the Pickering to the west end of the pond. In the late 1930's this source dried up[2], and now the water source is a small creek originating at Milky Way Farm. It flows down the hill through a very rugged and densely wooded area owned by the Township, then through a field formerly owned by Elmer White, now also owned by the Township.

Until the late 1930's, during the winter months, the mill was frequently run twenty-four hours a day to keep up with the demand for feed. The original flow of water from the Pickering was adequate to run the mill continuously. The flow of water from the creek is totally inadequate for this purpose. At best, the creek supplies enough water to compensate for water losses due to pond leaks, infiltration and evaporation. For this reason, the mill operation now relies exclusively on water stored in the mill pond, the small holding pond and head race.

Production grinds place the highest demand on the water supply. It is not unusual for the pond level to drop four to six inches in a three to four hour period[3]. Beyond four hours, water flow from the mill pond to the mill becomes limited due to the relatively shallow head race. Although it was dredged in March of 2002[4], it has since filled in, and should be dredged again. Ideally, the bottoms of the small holding pond and head race should be the same depth as the mill pond.

It is useful to determine the actual flow rate of water into the mill during peak usage periods. If this is known, then the power and torque provided by the water wheel can be calculated. Water usage data has been collected for all production grinds since 2008. This data includes the water level at the beginning of the grind, the water level at the conclusion of the grind, and the time duration of the grind. The data for eight sample grinds over this period[5] indicates that the pond level drops an average of 1.39 inches per hour. The total water area of the mill pond, the head race and the small holding pond is 37,755 square feet (see appendix A). The volume of water in each inch of depth is 3,146 cubic feet of water, or 23,535 gallons. 1.39 inches of depth contain 32,714 gallons, and this is the water volume used per hour. This results in an average water usage rate of 545 gallons per minute.

A completely different method of calculating water flow is based on the height of a column of water and the flow rate at the bottom of the column through a one inch by one inch orifice (see Appendix B). From the data that has been collected, the average height of water in the forebay is 39 inches:



From the table in Appendix B, a head of 39 inches provides a discharge of 3.77 cubic feet per minute through a one inch by one inch orifice. The maximum area of our opening is 11/16” times 31 inches, or 21.313 square inches. This multiplied by 3.77 gives 80.348 cubic feet per minute, or 601 gallons per minute.

The average of these two results will be used, which is 573 gallons per minute.

Water Wheel Power and Torque

The amount of torque provided by the water wheel is determined by the weight of water in each bucket. It is a mistake to assume that the water wheel buckets are completely filled. According to millers' lore, the buckets rarely fill to more than twenty per cent of their capacity. Having calculated the water flow rate, and knowing that the water wheel turns at the rate of approximately eight revolutions per minute, the amount of water in each bucket can be determined. Forty-eight buckets are filled in each revolution. In eight revolutions, 384 buckets are filled. If the flow rate is 573 gallons per minute, then the amount of water in each bucket is 573 divided by 384, or 1.49 gallons. The bucket capacity is 5.84 gallons[6]. This means that each bucket is filled to 26 per cent of its capacity at maximum flow. The old millers were right!

In Appendix C, the relationship between torque, power and R_{pm} is given by

$$T = P/2\pi R_{pm}$$

This is an important relationship in terms of its applicability to our mill. If the power remains constant, which means that the water flow doesn't change, and if the machinery starts bogging down for some reason, resulting in a decrease in R_{pm}, then the torque T will increase. Intuitively, this is understandable. As the water wheel slows down, and the same amount of water is still flowing in, then each bucket will be filled with more water. This increases the torque, which puts additional strain on the machinery. An unfortunate consequence of this was experienced during a production grind in November of 2010. At the end of the grind, a different variety of wheat was introduced which happened to be smoother flowing. Suddenly the flow of wheat into the stones increased, and the machinery started slowing down. Before the water flow could be reduced, the torque increased to the point where a cog on the master gear snapped off.

Using the relationship above, the torque can easily be determined by first calculating the power. If Q is the flow of water in gallons per minute, and d is the weight of the water in pounds per gallon, then the power $P = Qd2r$, where

2r is the distance the water falls (twice the radius of the water wheel). This gives P = (573)(8.34)(16) = 76,461 foot-pounds per minute. In units of horsepower, this is 76,461/33,000 = 2.32 horsepower. The torque is $76{,}461/2\pi R_{pm}$ = 1,521 foot-pounds.

An entirely different approach to calculating torque is given in Appendix D, where T = 15.258 r W. The weight of water in each bucket, W, is 1.49d = (1.49)(8.34) = 12.43 pounds. Therefore, T = (15.258)(8)(12.43) = 1,517 foot-pounds. This result is consistent with the prior result, and serves to validate the two approaches.

Mill Machinery

The hurst frame supports the millstones and machinery. It is a timber frame structure that is self standing, and is isolated from the frame and walls of the mill building so that the walls are not damaged by the vibration of the machinery.

The purpose of the gear train is to transfer the power generated by the water wheel to three vertical shafts, or spindles, which turn the runner stone of each of three pairs of stones.

The master gear (also called pit gear) is mounted directly on the same shaft as the water wheel by virtue of a retrofit square iron casting at the center of the wooden master gear. The master gear turns at 8 rpm, as does the water wheel, and it turns clockwise as viewed from the front. The master gear is approximately 10 feet in diameter, and has 78 cogs. It was rebuilt from the original pattern in 2002.

The gear train is a counter shaft gear system. The master gear drives a left counter shaft for the feed stone, and a right counter shaft for either of two flour stones.

The master gear meshes with two lantern gears called wallowers, one of which drives the left counter shaft, and one of which drives the right counter shaft. The left wallower has 21 rounds, and the right wallower has 23 rounds.

The counter shafts are engaged and disengaged using counter shaft levers. Pushing the lever forward engages the counter shaft, and pulling it back disengages the counter shaft. When engaged, a wedge block is inserted behind the moveable counter shaft bearing block to insure that the counter shaft remains engaged.

Due to the clockwise rotation of the master gear, there is an upward force on the left counter shaft, and a downward force on the right counter shaft. For this reason, the left counter shaft bearing block has a tenon which fits into a mortise in the hurst frame post as well as a hand wheel which must be tightened to secure the counter shaft in position (in addition to the wedge block). Since the force on the right counter shaft is downward, neither a tenon nor a hand wheel is required.

Face gears on each counter shaft convert the horizontal rotation of the counter shaft to the vertical rotation of the stone spindles. The face gears are approximately 5 feet in diameter. The left counter shaft face gear has 44 cogs, and the right counter shaft face gears have 36 cogs.

A pinion gear called a stone nut (or stone pinion) meshes with the face gear to drive the vertical spindle. Originally, the stone nuts were wooden lantern gears. Two were replaced by cast iron gears, but one of these was changed back to the lantern gear during the restoration. The remaining cast iron gear can be lifted off a cast iron hub to disengage the spindle.

Each vertical spindle supports the entire weight of the runner stone above (3200 pounds in the case of the feed stone). The spindle goes up through the eye of the bed stone, which is stationary, and it drives the runner stone which is positioned above the bed stone. The bottom of each spindle is supported by a cast iron bearing called a tram pot, which is recessed in a cavity in the bridge tree.

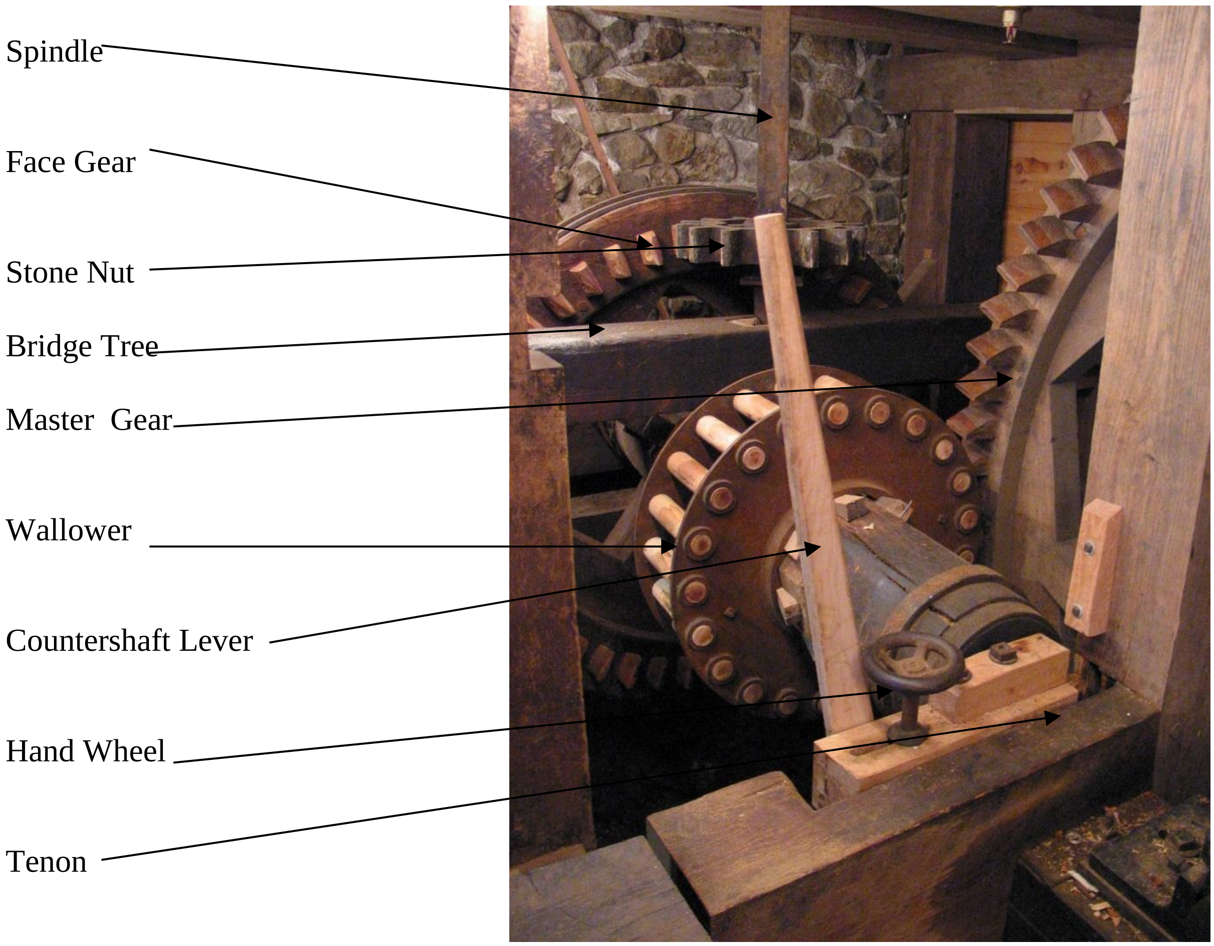
Each bed stone is supported by the hurst frame using two stone beams.

If the water wheel turns at 8 rpm, the feed stone turns at 93 rpm, and the flour stones turn at 70 rpm.

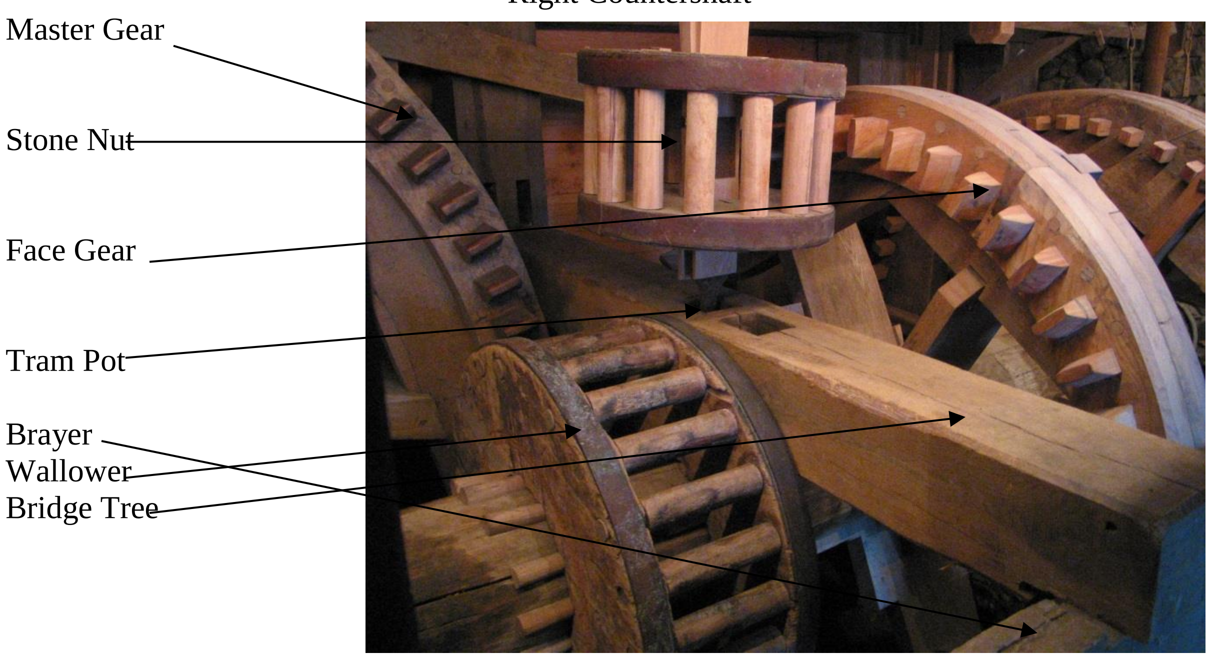
Tentering is the term applied to raising and lowering the runner stone to adjust the spacing between it and the bed stone, which determines the fineness or coarseness of the meal. The bottle beam (also called a lighter staff or tentering staff) raises or lowers the spindle and runner stone by minute amounts to accomplish this. A leather strap wrapped around the end of the bottle beam, secured by a bottle weight, keeps the bottle beam positioned exactly where the miller wants it set. The bottle beam leverages the brayer (beam) up or down which, in turn, moves the bridge tree (beam) up or down. The brayer supports the bridge tree which, in turn, supports the spindle.

The miller has three mechanisms to control the milling process. One is the tentering adjustment described above; a second is the control of the flow of grain into the eye of the stone using the crook peg. Turning the crook peg clockwise to tighten the leather strap raises the front end of the shoe and reduces the flow of grain into the eye of the stone. The third mechanism is the flow of water out of the chute onto the water wheel. A vertical gate control arm at the far left end of the hurst frame is connected to the control gate in the forebay. Raising the control arm reduces the water flow, and lowering it increases the flow. Its position is fixed at the desired flow by positioning it on the dowel pin at the appropriate hole.

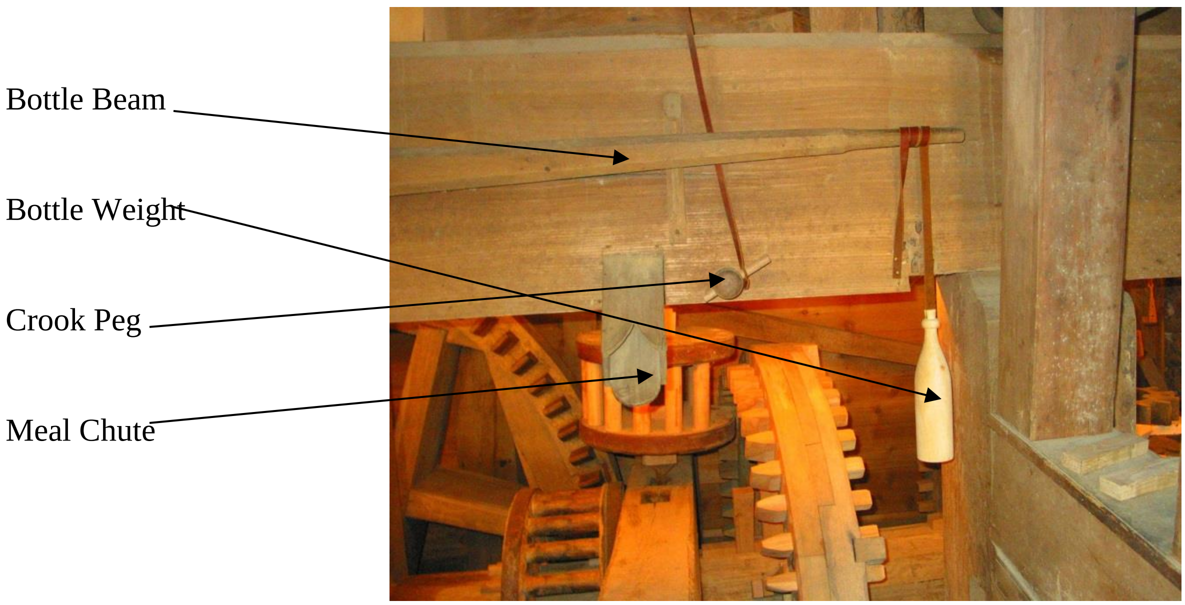
Left Countershaft



Right Countershaft



Bottle Beam



Millstones and Millstone Furniture

A pair of millstones, or a stand (also called a run) of millstones consists of a bedstone (stationary) on the bottom, and a runner stone (rotating) on top. The stones are dressed to produce a geometrical pattern of lands and furrows which crack and grind the grain. As the grain progresses outward from the eye, it is ground successively finer, and it emerges at the periphery at the desired fineness. The stones are spaced close together, but never actually come in contact.

The dress of the stones is extremely important in the grinding process. Different dresses are required depending on the direction of rotation of the stones (our feed stone turns counter clockwise, one flour stone turns clockwise, the other flour stone turns counter clockwise) and whether they are to be used for grinding feed corn or wheat. As a feed mill, the milling season ran from November to May, and during this period the stones would typically be dressed twice. This was a very laborious process which typically took a week and a half to complete.

Millstones are of two types, French burr stones or domestically quarried solid stones. The French burr stones are made up of segments (as many as 30) which are cut to shape and cemented together. Iron bands are heat shrunk on the outside, and a thick plaster of paris backing is applied. These stone segments were quarried in France, in the Marne Valley, east of Paris. The solid stone is a granite conglomerate quarried in Tucker Hill, Virginia. The French burr stones were used to grind wheat, and the granite stone was used to grind feed corn.

At the center of the bed stone is a neck bearing, or bushing for the spindle which comes up from below to support and turn the runner stone. The driver is an oblong, hand wrought piece of iron which fits over the spindle and rotates with the spindle. The ends of the driver fit into recesses in the runner stone to rotate the stone.

The rynd is a curved piece of iron cemented into the runner stone. At the center of the rynd is a socket called the cockeye which fits over the top of the spindle which is called the cockhead. The entire weight of the runner stone is supported by the rynd on top of the spindle. The runner stone is perfectly balanced on the cockhead. The socket of the damsel fits over the top of the rynd so that the damsel rotates as the stone rotates.

The stone crane is used to lift the runner stone off for maintenance and dressing. It consists of a jack screw and two bales which are attached to holes on either side of the runner stone by steel pins. When the stone is raised it can be inverted on the pins to turn the underside up for dressing. One stone crane serves both flour stones, and the other is used for the feed stone.

The millstone furniture consists of a hopper, horse and shoe assembly, and a wooden hoop (also called a case or vat or tun) surrounding the millstones on which this assembly sits. The purpose of the millstone furniture is to guide the grain into the eye of the runner stone at a constant rate. The hoop contains the ground meal and guides it to the opening in the floor and down the meal spout.

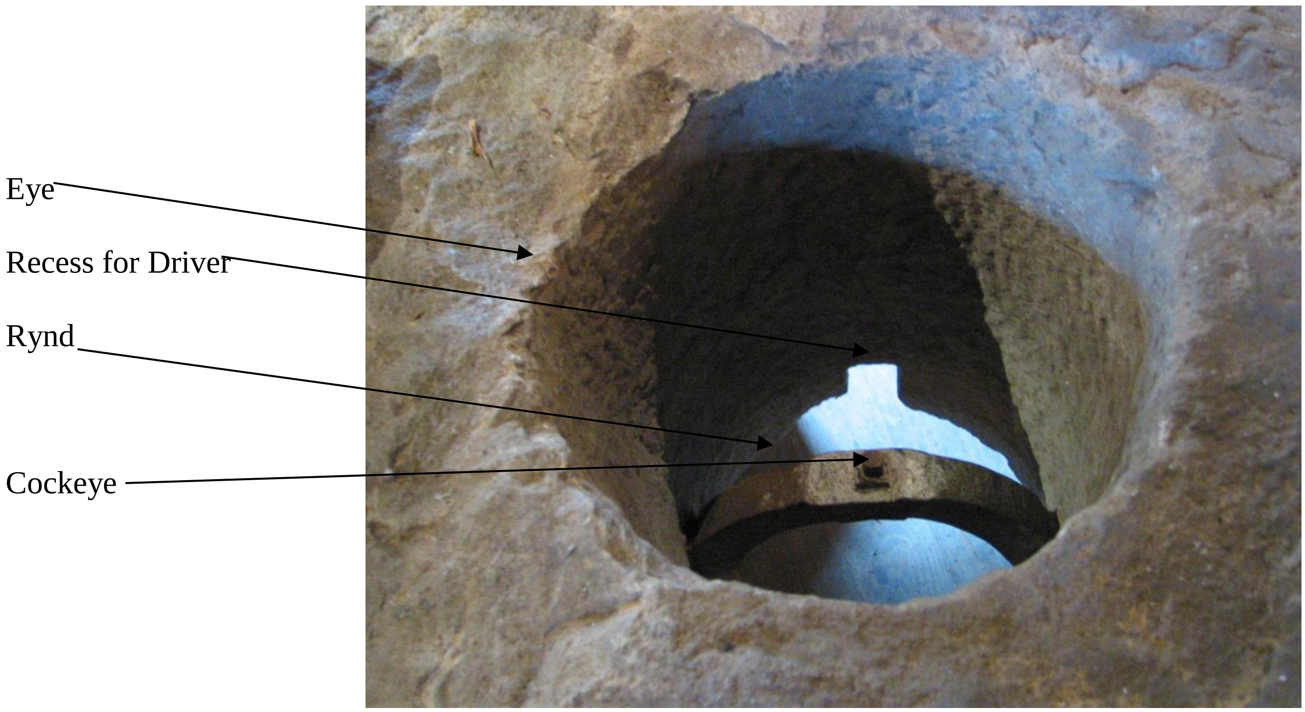
The hopper is a large square wooden “funnel” that collects the grain from the chute above and guides the grain onto the shoe. The hopper fits on the horse, a wooden frame which also supports the shoe.

The front of the shoe is raised up or down by a crook line attached to the crook peg. When the crook line is tightened, the angle of the shoe decreases, and less grain flows into the eye of the stone.

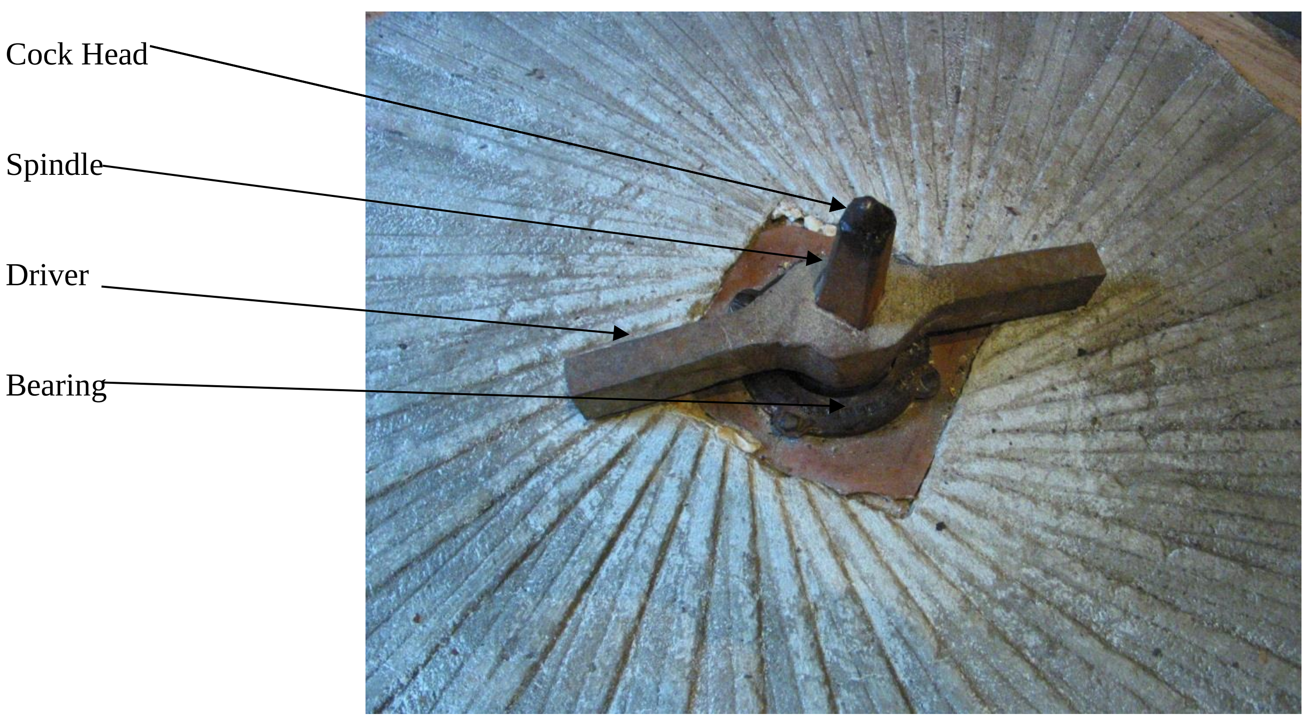
The shoe is vibrated by means of the damsel which rotates with the runner stone and raps against the side of the shoe as the stone rotates. A wooden spring on the horse applies pressure to the shoe against the damsel as the stone rotates. The damsel strikes the rap on the shoe as it rotates.

Millstones

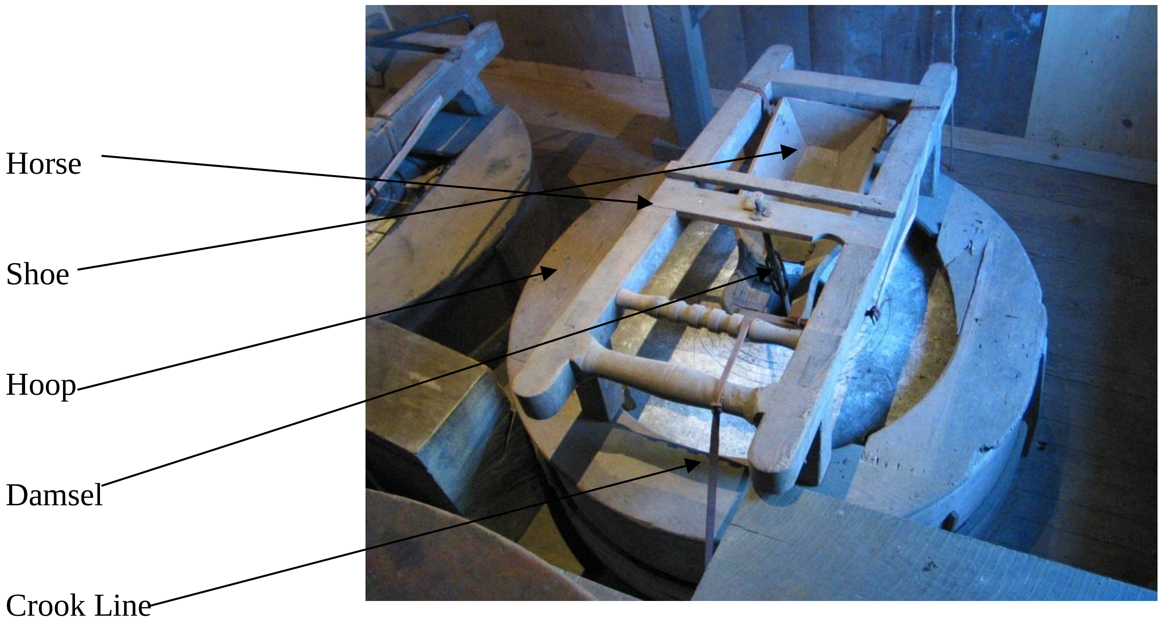
Runner Stone

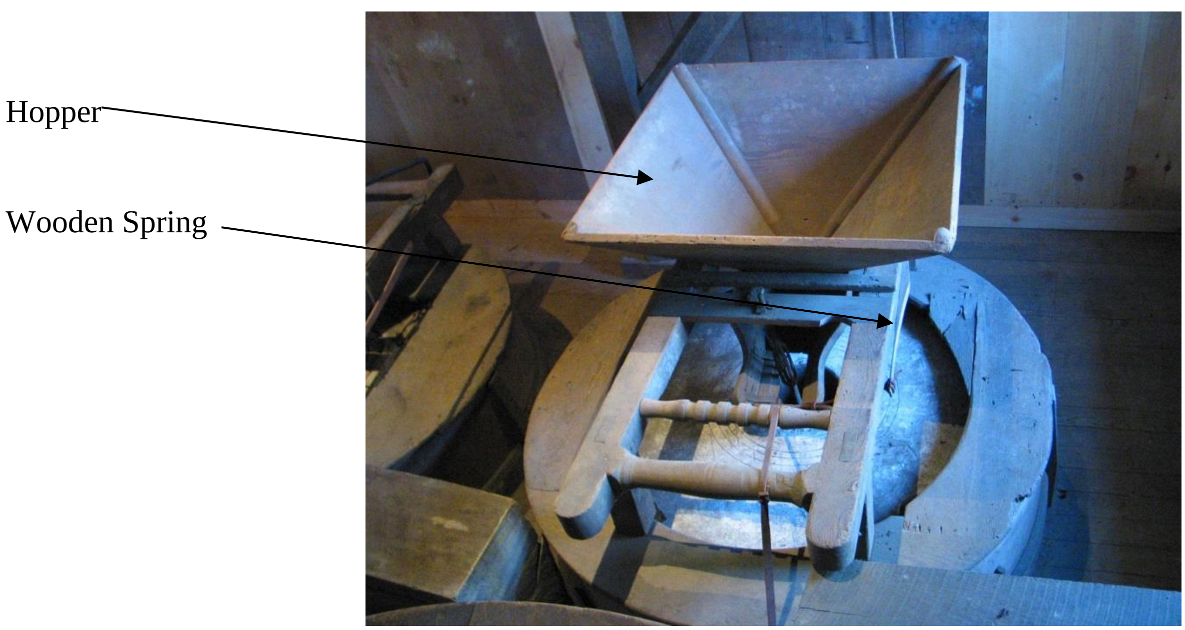


Bed Stone



Millstone Furniture





Appendix A
Pond Area Calculation

The areas of the mill pond and the small holding pond can be calculated using an area calculator in the Google Earth Pro software, in exactly the same way a planimeter would be used. The perimeter of each pond is traced, which is shown in yellow in the accompanying Google Earth pictures. The area of the head race is determined by tracing its length, then multiplying by the width of the head race, which was measured. Finally, a correction for the conduit constriction under the railroad bed was applied:

Mill Pond		32,000 sq ft
Small Holding Pond		2,365 sq ft
Length of Head race	280 ft	
Width of Head Race	X13 ft	
	3640 sq ft	3,640 sq ft
Correction for Railroad Bed		(325) sq ft
Conduit Area		75 sq ft
	Total	37,755 sq ft


Google earth
© 2011 Google
feet 400
meters 100
Google Earth Pro
32,000 ft²


Google earth
© 2011 Europa Technologies
© 2011 Google
feet
meters
200
80
280 ft

2365 ft²

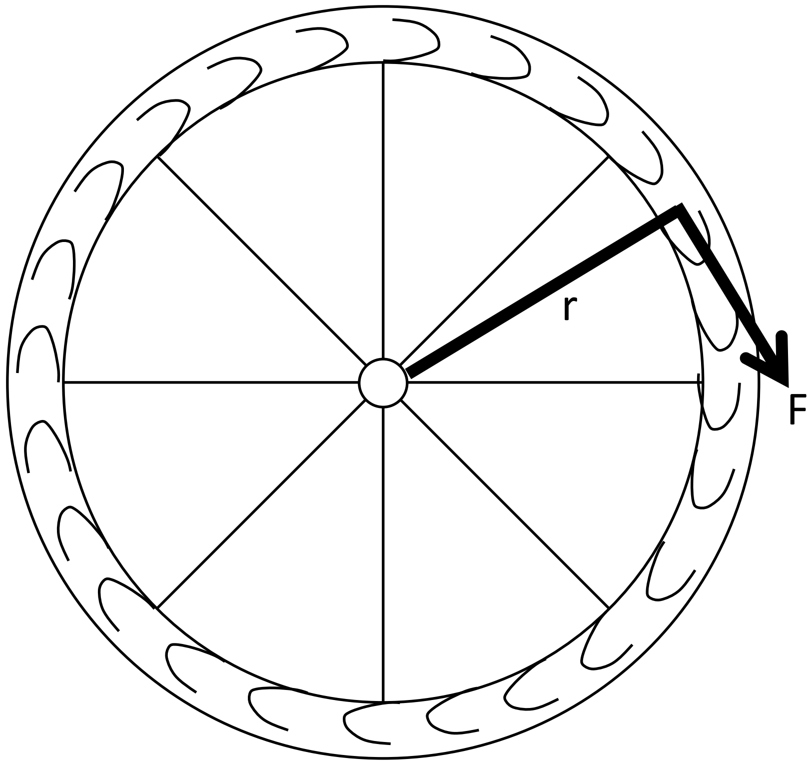
<u>Appendix B</u>

<u>Flow Rate of Water Under Pressure</u>

The following table gives the flow of water in cubic feet per minute discharged through an opening one inch by one inch for any head 3 inches to 62 inches[7]:

Head	Cubic Feet	Head	Cubic Feet	Head	Cubic Feet	Head	Cubic Feet	Head	Cubic Feet	Head	Cubic Feet
3	1.12	13	2.20	23	2.91	33	3.47	43	3.95	53	4.39
4	1.27	14	2.27	24	2 97	34	3.52	44	4 00	54	4.42
5	1.41	15	2.36	25	3.03	35	3 57	45	4.05	55	4.46
6	1.53	16	2.44	26	3.09	36	3 63	46	4.10	56	4.52
7	1.64	17	2.51	27	3.15	37	3.67	47	4.13	57	4.55
8	1.75	18	2.58	28	3 20	38	3.72	48	4.18	58	4.58
9	1.85	19	2.65	29	3.26	39	3.77	49	4 22	59	4.63
10	1.94	20	2 72	30	3.32	40	3.82	50	4.27	60	4.66
11	2.03	21	2.78	31	3.37	41	3.86	51	4 30	61	4.72
12	2.12	22	2.85	32	3.42	42	3.92	52	4.34	62	4 74

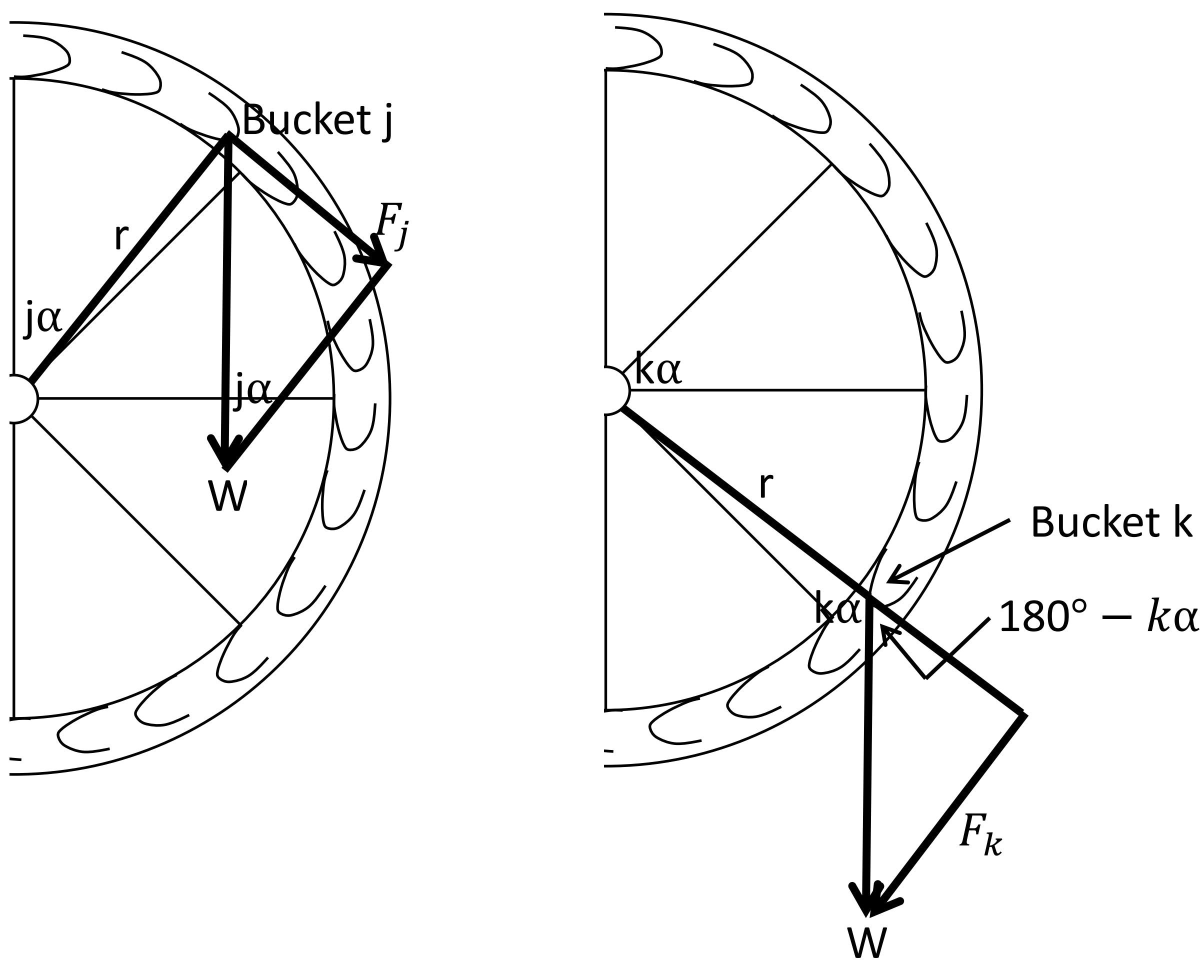
Appendix C
Torque Derivation
Dynamic Method



In this method, the torque on the water wheel shaft due to the water in the buckets is replaced by an equivalent torque due to force F and moment arm r. The work done by force F in one complete revolution is the force F acting through the distance 2πr. This is 2πrF. Power is the work done per unit time. The time for one complete revolution is $1/R_{pm}$, so the power P is given by 2πrF divided by $1/R_{pm}$, or P = $2\pi rFR_{pm}$. The product rF is the torque, T, so the result is the following:

$$P = 2\pi TR_{pm} \qquad T = P/2\pi R_{pm}$$

Appendix D
Torque Derivation
Static Method



In this method, the water wheel is assumed to be stationary, and each bucket contains an amount of water of weight W. The torque contributed by each bucket is calculated, and the total torque T is the sum of all the individual torques contributed by the buckets.

If N is the total number of buckets (48 in our case), the total torque T is the sum of the individual torques for buckets on the downward half of the water wheel:

$$T = \sum_{n=1}^{N/2} T_n$$

The torque contributed by each bucket is determined by the component of the weight of the water in that bucket tangential to the water wheel (perpendicular to the radius r). In the preceding two diagrams, this component is F_j for bucket j, and F_k for bucket k. The torque in each case is this component multiplied by the radius r:

$$T_j = rF_j$$

$$T_k = rF_k$$

With N buckets, the angle α between any two buckets is $360^0/N$.

Calculating the forces F_j and F_k,

$$F_j = W \sin(j\alpha)$$

$$F_k = W \sin(180^0 - k\alpha) = W \sin(k\alpha)$$

The individual torques then become:

$$T_j = r\, W \sin(j\alpha)$$

$$T_k = r\, W \sin(k\alpha)$$

The total torque T is the sum of all the individual torques:

$$T = \sum_{n=1}^{N/2} r\, W \sin(n\,\alpha) \; = \; rW \sum_{n=1}^{N/2} \sin(n\alpha) \; = 15.258\, r\, W$$

Where N = 48, and $\alpha = 7.5^0$

Appendix E
Water Wheel Specifications

- Manufactured by The Fitz Water Wheel Company (including forebay and chute)
- Installed sometime 1906-1909 (Allen Simmers era)
- Restored in 2001-2002 by Pottstown Metal Welding Company under direction of Jack Brogan and Stephen Kindig. Used original arms, shaft and bearings. Replicated rim and buckets
- Overshot water wheel (as opposed to pitch back, breast shot or undershot)
- Diameter: 16 feet, 4 inches
- Assembled in 8 sections
- 48 buckets, each bucket capacity 5.8 gallons
- Weighs approximately 3,500 pounds
- Designed to turn at 8 rpms
- Designed to be compatible with existing wooden gear system
- End of chute positioned approximately 9 inches before top dead center. Chute distributes water evenly across width of buckets
- Buckets designed to minimize spillage and retain water all the way down to tail race. Hole in each bucket reduces vacuum to empty water as quickly as possible
- Forebay holds 286 gallons of water when completely filled
- Forebay measures approximately 3 feet by 3 feet by 4 ½ feet
- Forebay weighs 600 pounds empty
- Forebay control gate controls flow of water through chute onto water wheel
- Pipe diameter leading into forbay is 18 inches

Appendix F
Footnotes and References

1. Kate Saltanovitz, Restoring Water Supply to The Mill at Anselma, pg 23
2. Mill at Anselma, Information Brief 1, pg 3
3. Dave Rollenhagen, Miller's Journal, pg 76
4. Kate Saltanovitz, pg 27
5. Dave Rollenhagen, pg 76
6. Kate Saltanovitz, pg 10
7. Fitz Water Wheel Company, Fitz Steel Overshoot Water Wheel, pg 66