THE DEVELOPMENT OF A CHAIN AND WASHER PUMP
FOR SMALL SCALE IRRIGATION
(Research Project AE/ip 3.1 1977)
BY
H.S. PEARSON AND ARAYA KEBEDE

Addis Ababa
April 1980
INRODUCTION:

In 1976 it was decided to study and develop suitable low lift water pumps for small scale irrigation. The basic criteria for such pumps was that they should be suitable for local manufacture, cheap to produce, easy to maintain & cheap to operate using locally available sources of power (wind, water, animal or human).

The most promising type of pump for such a purpose was considered to be a chain & washer type. A research & development programme was therefore put into operation at the Appropriate Technology for Farmers (ATF) workshop at the Nazareth Research Station of the Institute of Agricultural Research (IAR).

The chain and washer pump system is very simple and, unlike most pumps, does not require valves. It is also possibly the oldest form of rotary pumps in the world after the Persian wheel. The system works as follows - (see drawing DR 1.) A drive wheel (1) pulls a continuous loop of chain (2) through the lift pipe (3). Fitted to this chain are circular washers (4) which fit closely to the inside diameter of the lift pipe. Rotation of the drive wheel draws the chain up the lift pipe, water is trapped between the pump washers spaced on the chain and lifted to the outlet (5) at the top of the pipe. A bell-mouth (6) helps the washers to enter the pipe smoothly.

Practical maximum lift with this type of pump is said to be twenty metres, but this would depend, among other things, on the bore of the pipe, speed and available drive force. It is also possible that at depths over twenty metres the length of the chain would become unmanageable. In practice it is preferable to restrict the height of lift to about 15 metres.

The reasons for choosing this pump design are as follows:
1. Low working speed making it possible to use the low grade materials available locally.
2. Construction is such that the pump could be manufactured in a rural workshop with limited equipment.
3. This type of pump has shown itself to be effective in use; details of tests in Ethiopia are given later in this report.
All the working parts are easily seen and, when running, this type of pump can be used in the technical education of its users. Specific features of interest are:
- transmission of power from ox (or wind) for use in lifting water;
- change in direction of power through 90°;
- use of simple gears;
- how bearings function; and
- chain and pump washer action.

The basic aim when the ATF team decided to develop a chain pump was to find a design that could be used to irrigate small areas such as horticultural plots. Therefore, the design that has been developed would not be very suitable for supplying domestic water needs as the flow for domestic requirements is generally lower than that needed for irrigation. This is not to say the pump could not be used to supply water to a village under suitable conditions, i.e., where a river or shallow well is available. Delivery details are given later in this report.

**DEVELOPMENT OF THE CHAIN PUMP AT THE ATF UNIT**

Work started on the development of a chain pump in early August 1977 at the ATF workshop in Nazareth. A tower was constructed to give a test lift height of five metres.

During all the early tests, the pump was operated by turning a crank handle mounted directly on to the drive wheel. This gave a drive speed of 20 to 30 r.p.m., but due to the load, this could not be sustained for more than one minute by one man. Later for test purposes and long-term running tests a low-speed (60 r.p.m.) geared electric motor was used; the speed was first reduced to 30 r.p.m. and then later 20 r.p.m.

**Pump Components**

*Pipes* - (3) in DN 1. Plastic drain pipe with a 72 mm bore was chosen. At 5 Eth. Birr (US 2.50) a metre of this type of pipe is expensive but has the advantages of being:
- non-corrosive in water;
- flexible enough to bend;
- light and easy to work with.
Chain and Washer Pump

1. Drive Wheel
2. Chain
3. Lift Pipe
4. Pump Washers
5. Outlet
6. Bell Mouth Entry

Diagram: Chain and Washer Pump

- Drive Wheel
- Chain
- Lift Pipe
- Pump Washers
- Outlet
- Bell Mouth Entry

Diagram Elements:
- Chain and Washer Pump
- Water Level
- Ground Level

Diagram Details:
- Drive Wheel
- Chain
- Lift Pipe
- Pump Washers
- Outlet
- Bell Mouth Entry

Diagram Notes:
- Water Level
- Ground Level

Diagram Orientation:
- Orientation indicates flow direction from drive wheel to bell mouth entry through lift pipe and pump washers.
Alternative materials, such as steel pipe, are available but the cost is as high without the advantages mentioned above.

System 1. (DR1)

Drive wheel: In the early stages of development the drive wheel consisted of a steel structure 40 cm in diameter with six sides. Each of these sides had 2 wood blocks for driving the chain - see DR 2.

Chain and pump washers - DR 2-1: The chain on this early model was made of 4 mm diameter iron wire 18 cm long with a ring at each end; the links were joined with rings 15 mm in diameter. The links were held in place on the links by two small steel washers welded to the links. The wooden pump washers were used to drive the chain as they rotated over the drive wheel - each washer sitting between the wooden blocks on the drive wheel. These pump washers were made of soft wood soaked in hot used engine oil. Later in the development wooden washers were discarded.

Problems with System -1.

Drive wheel: The drive wheel itself did not give many problems, but its construction was too complicated and material intensive. Attachment of the wood blocks to the wheel gave some problems as the wood became loose because it expanded when wet and then contracted when dry. It was also felt that the wheel may not have been large enough in diameter for effective long-term work.

Chain and pump washers: The chain itself was no problem to manufacture and the 4 mm wire was inexpensive. However, it was found then as well as later in the development that it was not a good idea to drive the pump through the washers. The wooden washers tended either to fail to enter the spaces on the drive wheel, or jam on exit. The fault was in the depth of engagement of the pump washer on the drive wheel which was 35 mm - equal to half the diameter of the pump washer.

The pump washers were made of soft wood soaked in old engine oil which had been heated. A total of 2 mm clearance (1mm all round) was given between the washers and the lift pipe. This may seem a lot but with a pipe 5 m long and washers spaced at 20 cm there would have been 25 washers at any one time in the pipe. Each washer was 25 mm wide and thus there would have been 625 mm of contact between the pipe and the washers. If the washers fitted the pipe too well this 625 mm would represent a great amount of friction between the washers and the pipe. The 2 mm clearance given allowed for water to pass between the washer and the wall of the pipe. This water acted as a lubricant and kept the frictional losses to a minimum including wear on the walls of the pipe.
SYSTEM No 1
DR No 2
DRIVE WHEEL

WOOD BLOCKS

Scale = 1/4 Full size

DR No 2-1
CHAIN AND PUMP
WASHERS

JOINING RING
WOOD WASHER

Scale = 1/2 Full size

CHAIN AND WASHER
CONSTRUCTION

Scale = 1/8 Full size
In action the pump did not run smoothly and tended to jam as the chain and washers tode over the drive wheel. One reason for this has been explained in the problem of engagement of the pump washers on the drive wheel. A more serious problem was that the chain tended to become 'link locked'. The explanation this that as the chain rotated a twisting action took place as the chain curved to enter the lift pipe and this caused the links to lock. This locking that changed the pitch dimension of the chain so that it no longer fitted the drive wheel.

System 2

System 2 was similar till. The only changes made were that the pitch of the chain was halved by shortening the length of the links. This gave more flexibility in the chain resulting in smoother running over the drive wheel. However, the 'link locking' still persisted.

System 3

In system 3 the chain was changed in favour of dog lead chain. This chain is available locally at Eth. Birr 1.50 a meter. The chain links are of 3 ofmm diameter chrome plated wire twisted to form a figure-of-eight. The wooden pump washers were still maintained at this stage.

The wooden blocks on the drive wheel were replaced by box tube sections 30 x 30 x 100mm welded to the existing six-sided metal wheel.

This system worked better than systems 1 and 2. The chain ran more smoothly over the drive wheel and did not lock when moving round the bend before entering the pipe. The wooden pump washers were spaced at 32cm so that at any one time there were 2 washers in the driving position on the wheel.

Problems with system 3.

Pump washers: With prolonged running the pump washers slipped over the drive wheel; they also started jamming in the lift pipe. The reason for the jamming was traced to swelling of the wood. The washers in use on the pump had expanded by 2-3mm. Tests were made on un-used washers. These were soaked in water for three days and then measured. The diameters of the water soaked washers were no greater than the non-soaked washers. We feel what the reason the working washers expanded was because they were working under hydraulic pressure (the washers we soaked were not) and water was being forced into them even though they had been soaked in hot oil.
This situation may not have arisen had we used hard wood in making the washers. However, we felt that at some time soft wood would be used by some local artizan if hard wood was not available. Some of the washers also started to show signs of splitting due to the constant wetting and drying.

After the experience described above, it was decided not to use wood for pump washers on chain pumps that were to be used for large volumes and/or depths of over two meters. However, wooden washers could be used on small domestic pumps where the lifting requirements and volumes are small. Even so it is recommended that only hard wood be used.

**Drive system:** As stated above, the wooden washers tended to slip over the drive wheel. With the decision to change the drive system and to drive the pump from the chain and not from the washers. This would not only give a more positive drive, but would also mean that the spacing of the washers on the chain need not be related to the design of the drive wheel.

**System 4 (DR 3)**

**Drive wheel:** The new drive wheel was circular at the rim and had 14 drive pegs (80 mm x 50 mm x 10 mm) set at a pitch of 128 mm. This gave a rim diameter of 450 mm. See drawing DR 3-1 for the details of the drive pegs.

**Chair (DR 3-2):** The chain links were bent up on a jig made in the workshop to ensure uniformity. See drawing DR 3-2 for details of the chain.

**Pump washers (DR 3-3):** After some thought a suitable design was drawn up for the pump washers, DR 3-3 shows the construction. Steel plates were cut square for ease of manufacture. The plates were cut with a slot into which the chain would fit and then jig drilled to ensure accurate assembly. Rubber sealing washers were cut from heavy motor inner tube (such as Land Rover). They had two holes punched to fit the chain with a cut made at 45° for assembly.

The plates and link were assembled with the rubber washer in place: the plates being clamped whilst two small welds were made between the link and the plates. With the drive being through the chain it was not necessary to have the washers so closely spaced; they were placed at 38 cm intervals.

**Testing:** In practice system 4 did not work at all well. It had been expected that the chain would be self-aligning with the rotation of the drive wheel. This was not the case and the links tended to twist on one side and not engage on the drive pegs. However, for short periods the chain would run correctly and when it did so the pump ran very smoothly.
Drive Wheel
Scale = 1/4

DR No 3
System No 4
Drive Wheel

DR No 3-1
Detail of drive pegs
Scale = 1/2
SYSTEM 4

- DR No 3-3
  - Pump Washer
  - Exploded View

- LINK
- RIVETS

- FLAT PLATE
- RUBBER WASHER
- FLAT PLATE

DR 3-2

Scale=Full Size
Another problem was that the drive wheel was reluctant to release the chain. The dead weight of the water in the 5 metre lift pipe was about 20 kg (this load increases as the lift gets greater).

Engagement of the chain on the drive wheel must be positive on the lift side whilst the chain must release readily on the drop (down)side.

At this point it would be useful to list the problems identified as system 5 has become the final system which overcomes these earlier difficulties.

1. Wooden pump washers were not found suitable for heavy duty pumps with long running periods, such as are needed for irrigation.
2. Long chain links tend to bend when going over the drive wheel.
3. When moving the chain tends to twist around its own axis which gives problems of chain alignment over the drive wheel.
4. Driving the pump from the piston washers puts too much strain on the washers and is not positive enough.
5. With pegs for chain driving, the chain tends to slop off the drive wheel on the lift (up) side and/or jam on the release (down) side.

System 5 (Dr 4)

As a result of the development of systems 1 to 4, in particular information gained from work carried out on system 4, a final positive result was achieved with system 5. The basis of this system is the drive wheel and construction of the chain. In system 4 a peg engaged with the ring of the link to provide the drive; System 5 uses an opposite system with a fork engaging with the intermediate links of the chain—see drawing DR 4.

Drive wheel (DR 4-1): The drive wheel is of the same dimensions as in system 4 but a fork arrangement is used to drive the chain. The forks are made up of 3 flat pieces of metal put together as in DR 4-2: 14 lighting forks are set equal distance apart around the 450 mm diameter rim of the drive wheel and welded in place. The drive wheel runs on hard wood bearings and has a ratchet device to prevent the pump from running backwards.

Chain (DR 4-3): The chain is made up two types of links: plain oval links (free links) and intermediate drive links which have a ring or loop at each end—see DR 4-3 for details of the links. The important factor with the chain is that it must be accurately constructed. If the links are not consistent in length the pitching will change resulting in poor or rough running and jamming.
PUMP WASHERS

DR No 4
SYSTEM No 5

General arrangement of chain engagement
System 5, on test pump driven by electric motor, Nazareth ATF unit
Drive Wheel

Scale = 1/4

DR No 4-1
System No 5
Drive Wheel

DR No 4-2
Detail of drive forks

Scale = 1/2
Fixtures were made in the workshop to ensure that the links of the chain were accurate. The chain was constructed from 6 mm iron. It is not welded.

**Pump Washers (DR 4-4):** Several changes were made in the design of the pump washers. A tool constructed to punch out round metal discs 6 cm in diameter. These discs had a hole punched in them off-set from the centre and through which the closed side of the plain chain link is threaded. Each washer consisted of two metal discs either side of a rubber inner-tube disc which was cut 2-3 mm bigger than the 72 mm bore plastic pipe. With this system slots are not needed in the rubber disc. For assembly only two small welds are required, one each side of the metal discs which fix the discs to the chain link and clamp the rubber in place.

**Running and Testing:** This system was first tested by turning the drive wheel by hand. It soon became apparent that the pump was working well and it would be possible to drive it for long periods using a low speed electric motor. A safety device in the form of a small pin 5 mm in diameter was included in the drive system: should any great overload occur the pin would break disconnecting the drive and preventing damage to the pump. The electric motor used was a 2 HP geared down to 60 r.p.m. For driving the pump it was further geared down first to 30 r.p.m. and later to 20 r.p.m. As there is far more power available than is required to drive the pump, the safety device is very much needed.

The first tests with the motor were at 30 r.p.m. (drive wheel speed) but this speed was found to be a little too fast as it tended to throw the chain off the wheel. It was also felt that this speed would be too high when using oxen or wind as a power source. The speed was therefore geared down to 20 r.p.m. Delivery of water at 30 r.p.m. was 260 litres a minute with a lift of 5 meters: with the drop in speed to 20 r.p.m. delivery dropped to 180 litres a minute.

Long term running tests started on 5 February 1979 and by 14 May 1979 the pump had been working for 500 hours. Records of all running have been kept on forms similar to the sample attached to this report. Some small modifications were required to the drive wheel during this time; however, it never had to be removed from the tower.
<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME START</th>
<th>TIME STOP</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SYSTEM 5

DR 4-4
Pump washer,
Exploded view

CHAIN LINKS
(Driving link)

FREE LINK

FLAT PLATE

RUBBER WASHER

FLAT PLATE

Scale = Full size
After the first 125 hours of running one pump washer was removed in order to study the wear on the washers over time. Other washers have since been removed after each 125 hours of running. These washers have been replaced with new ones in order to keep the system balanced.

Testing has also examined the amount of submergence needed for the lift pipe. It has been found that maximum lift (5 metres in this case) can be achieved with only 15-20 cm of the lift pipe submerged in the water source. At first it was thought that the minimum depth for effective lift would have to correspond to the spacing of the washers on the chain. In system 5 the washers are spaced at 52 cm but effective lift is achieved with 15-20 cm submergence. The explanation is that the pipe once filled with water becomes air-tight and a vacuum is formed at the entrance which causes water to rise up into the pipe. We found that with as little as 1 cm of the lift pipe (bell mouth) submerged there was little or no change in delivery of water. However, the deeper the pipe is in the water, the less is the effort required to lift this water.

Field testing: Using system 5 a double lift pump has been constructed in the ATF workshop. In this pump there is a single frame and drive shaft fitted with two sets of drive wheels, chains and washers and lift pipes.

This pump was installed on the ATF test well situated at Adama 27 km from Nazareth near the banks of the Awash river. The well is 10 metres deep with the water table at 7 metres. The pump was driven by oxen and delivered 200-250 litres a minute. It was found that the capacity of the pump was too great for the well. Therefore, it was decided to move the pump to the banks of the Awash river. A shallow pit 4 metres deep was dug and connected to the river by an underground pipe 6 metres long. Chains and lift pipes were shortened to 3 metres and the pump installed over the pit.

A local farmer has been using this pump to irrigate a quarter hectare plot of tomatoes. The pump is lifting 200-250 litres of water a minute. We feel that this is below capacity as the drive wheels were constructed to run at 20 r.p.m. with the pump being driven by oxen.

In fact the drive wheel speed is now about 14-15 r.p.m. A modification to the gear system will be made to correct this. The farmer's reaction has been good but the oxen being used are in very poor condition and are unable to operate the pump for more than one, or at the most two, hours at a time. The pump itself is not hard to turn and a small boy can push it round at oxen speed for 5-10 minutes.
/Please note that research on this pump is continuing and from time
to time new information will be added to this report to bring it up-
to-date. Anyone interested in this development is welcome to visit the ATP
workshop at Nazareth to study this or any other of our research projects/

**Technical details of the pump on test at Nazareth Research Station**

<table>
<thead>
<tr>
<th>DRIVE WHEEL</th>
<th>CHAIN</th>
<th>LIFT PIPE</th>
<th>PUMP WASHER</th>
<th>WASHER SPACING</th>
<th>MAX. DELIVERY AT 5m DEPTH</th>
<th>DRIVE WHEEL SPEED</th>
<th>CHAIN SPEED</th>
<th>PRODUCTION COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 mm ø</td>
<td>6 mm ø</td>
<td>72 mm ø plastic pipe /Local Manufacture/</td>
<td>rubber sealing discs between 2 metal plantes</td>
<td>52 cm</td>
<td>180 L/min</td>
<td>20 r.p.m</td>
<td>70 cm/sec</td>
<td>not yet finalized, further development required.</td>
</tr>
</tbody>
</table>