A literature study of

RESEARCH, APPLIED TO HAND- AND FOOT-OPERATED PISTON PUMPS
relating to dynamic behaviour, stress and fatigue

completed, continuing and planned research

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ABBREVIATIONS

CATR	Consumers' Association Testing and Research, Harpenden, U.K.
CWD/TUE	Consultancy Services Wind Energy Developing Countries/ Technische Universiteit Eindhoven, Eindhoven, The Netherlands
DHV	DHV Raadgevend Ingenieursburo, Amersfoort, The Netherlands
IAD	InterAction Design, Arnhem, The Netherlands
IDRC	International Development Research Centre, Canada
IRC	International Reference Centre for community water supply The Hague, The Netherlands
JV	Jansen Venneboer, Wijhe, The Netherlands
SWNV	Sociaal Werkvoorzieningsschap Noordwest-Veluwe Nunspeet, The Netherlands
VLOM	Village Level Operation and Maintenance
WB	World Bank

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0. FOREWORD

This literature study has been carried out, as part of the IAD Handpump project, to prepare own research programme.

The IAD Handpump project is aimed at enlarging the insight to the dynamic behaviour of hand- and foot-operated piston pumps and occuring stress. The measering programme assesses lifts up to 100 metres.

The project is approved and financed by the Nederlands Ministry for Development Cooperation.

Herewith I wish to thank the IRC for their cooperation with the literature study.

Project participators in the firts project phase are:
CWD, DHV, IAD, JV, SWNV.

Project co-ordinator:
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1. GOAL OF LITERATURE STUDY

To collect information concerning the aim and results of research elsewhere (completed/continuing/planned) in connection with the dynamic behaviour of hand- and foot-operated piston pumps, the occuring stress and fatigue:
1. to define precisely our own research programme, and
2. to use these results as guide-lines.

2. SUMMARY OF HANDPUMP RESEARCH

In general, research of hand- and foot-operated piston pumps for lifting water has a strong empirical character. Research is still concentrated on endurance and field testing.
During the early stage of development, a number of reliable pumps have evolved, however, the constricted applicability of such pumps in developing countries, due to high costs, the complexity of construction, and limited resistance to aggressive water, has made it necessary to further investigate designs which can be managed and maintained at village level (VLOM).
Except for endurance tests conducted by CATR/WB, empirical test results have hardly been published.

2.1 DYNAMIC BEHAVIOUR

Publications regarding empirical research of dynamic behaviour are scarce. Publications pertaining the derived design-rules are confined to slow-running piston pumps for deepwell oil pumping. [11, API].

Research of the dynamic behaviour of piston pumps for water lifting has, according to knowledge, been carried out by the University of Malaya only (hand-operated pumps) and by CWD (coupling to a windmill).

2.1.1 University of Malaya [4.3, Yau, G.S.]

The research of IDRC handpump ('Waterloo') by laboratory technicians under the direction of Goh Sin Yau, University of Malaya, Malaysia, was aimed:
1. To determine the influence of:
   - leakage along the piston,
   - piston valve weight, valve lift, and valve orifice,
   - piston stroke,
   - pump frequency,
   - lift,

   on the tensile stress in the pump rod head and the mechanical and volumetric efficiencies.
2. To judge their analytical model by comparing it to the test results.

The experimental rig consisted of:
- A 'Waterloo pump' sucking water from an open reservoir at constant water level and pumping it via the exit pipe into a tank. This tank rested on a weighing machine. The maximum real lift, tested was 8.25 metres.
- A driving unit consisting of a 0.75 kW DC motor with adjustible speed, a gear box and a cranck-rod system.
- A proof ring, mounted on the top end of the pump rod with 4 strain gauges to determine the tensile stress.
- A displacement transducer, with a slide resistance to determine the displacement of the top end of the rod.
- Strain gauge bridge conditioners, to amplify the signals.
- A 'Tektronix Digital Storage Oscilloscope 5223', to digitize the entry signals and transmit to the computer.
- An 'Apple-II' compatible computer, with data-acquisition programme, for retreiving, compiling and analysing the data, and to save and print the results.

Results consisted of:
- Data regarding measurements of above mentioned variables, in graphic form.
- A data-acquisition programme to use on the 'Apple-II'.
- A computer programme for calculating the mechanical- and volumetric efficiencies based on the constructive data input.
- An analytical model for calculating the dynamic tensile stress in the top end of the pump rod.

According to the researchers, the results acquired from the analytical model are in alignment to the measured values.

N.B. During the proofs, the pump was tested up and unto a lift of 8.25 metres only.

This programme based on earlier experiments at the University of Waterloo, Canada. The Waterloo experiments aimed at developing a PVC and PE pump (later the 'Waterloo pump'), whereby a restricted number of the above mentioned variables were examined. [4.1, Plumtree, A et al].

2.1.2 CWD [4, Smulders, P et al]

Similar experiments on piston pumps regarding coupling to windmills have been performed by CWD also. Measering of, among other, the pump rod stress and dynamic pressure inside the pump, were aimed at determining the dynamic aspects and to judge analytical models. The influences of valves (shape, weight and valve lift) and of a small calibrated leakage in the piston was tested as well as air chambers at the entry and exit of the cylinder: to constrain the starting torque of the driving unit and maximum tension in the pump rod.

Most of the experiments carried out at CWD were based on the following pump test rig:

- The 'Tanzania-pump', a single acting piston pump with a perspex cilinder, internal diameter 140 mm., with disc valves, coupled to
- Piping with a length of 80 m. to simulate line friction, and a pressure vessel, to simulate a head up to 100 m.
- Air chambers, at the entry and exit of the cylinder, where air content could be varied.

At recent experiments the following were measured:
- the tensile tension in the pump rod head, by means of a strain gauge force transducer,
- the velocity of the top end of the rod, by means of an inductive velocity transducer (moving magnet pick-up),
- the flow-velosity in the riser, by a flow meter (reacting on the induction current, caused by the flow current),
- the dynamic pressure; using different pressure transducers,
- the driving torque.

The amplified analogue signals were digitized via a A/D convertor. This convertor was part of a 'Metrabyte Dash-16' data- acquisition board. The data was stored in an 'IBM-XT', compiled and saved on disk, using the research workers' own written programmes based on the 'Asyst' software package.

Results of these experiments are:
- Data regarding the dynamic pressures in the air chambers and the tensile stress in the pump rod, as function of the amount of air in the air chamber and the pump frequency.
- An analytical model to describe the pressure fluctuations in the pump cylinder. [3.6, F. Verhey]

The results of a recent experiment regarding the closing behaviour of disc-valves can be found in [3.5, Cleijne/Smulders]. These are:
- An analytical model to describe the behaviour of foot- and pressure valves.
- Data concerning the influence of pump-frequency, valve lift and the specific mass of the valve.

According to the researchers there is a close correspondance in results between the measured and calculated values.

N.B. 1

The measering of the mechanical tension in the pump, during the different experiments were constrained to:
- the pump rod head,
- the gripe (for the driving wheel) or the handle respectively.

The chief goal was mostly to determine the relationship between input/output (mechanical and volumetric efficiencies), as a function of the following variables:
- the type of pump, and/or
- the (feigned) lift,
- the pump frequency,
- the valve lift,

- the valve weight,
- the diameter of the cylinder,
- the amount of air in the air chambers.

N.B. 2
By most deepwell pump experiments and tests the pressure head was 'feigned'. That is to say, to attain an indication of the stress in the mentioned pump parts, at the different pressure heads which could not be realised at the test side (more than 10 metres), a flow resistance was used in the riser and/or a closed system, to increase the pressure to feign the lift.
These methods were used by:
- CATR: 7,'25 and 45' metres,
- Georgia Institute of Technology: up to '100 metres',
- CWD: '20 to 100 metres'.

2.1.3 CATR

As part of the endurance tests, CATR measured the tensile stress at the pumprod head and the handle, respectively gripe, to deduce the mechanical efficiency. Furthermore, the main point of the research work was to determine the endurance capacity and user-friendliness. [1.X, WB/CATR].

At the moment preparations are being made for the 'Rising Main Project'. The Afridev and the India MKII are being tested to determine the stress in the top and bottom end of the riser, as a function of rising main suspension and the driver system. The system with the lowest stress results shall then undergo an endurance test of 15 month, in a 45 metre borehole. Also preparations are being made to determine the strain of the riser, particularly creep. The Afridev will be tested by the World Bank RPO, Nairobi and the India MKII by the CATR. [2.4, Mills, K.J.].

2.2 FATIGUE

Despite the fact that fatigue has lead to many pump failures, this phenomenon has practically only been empirically studied.

Main causes are probably:
- Underestimation of the problem (plays a part far after the sale!),
- The lacking of detailed information about the external forces acting at the pumps, while in use in the field, and the resulting stress in the various parts of the pump.

The most important documentated experiment, in this field, is the endurance test programme applied by CATR, in which handpumps are working for 4000 hours at (feigned) lifts, by a fixed scheme.
[5, WB/CATR]

Moreover, in various experiments, applied by manufacturers and independant research workers, construction details are tested for fatigue, but results have hardly been published.

From practical experience useful design rules have developed, among other, concerning the diameters of steel pump rods and connecting components, however, still with a restricted value specifically for higher lifts.

In general, there has been a lot of research which has been applied to the fatigue phenomenon: especially metals. Regarding synthetics far less is known. This has much to do with the large differences that exist in material properties, due to composition, production proces, influence of ultra violet light, temperature and age, etc, but also the fact that relative recent synthetic piping is used as a construction (riser) element, whereby the pipes also are exposed to long-term and variable axial tensile burdening.

Fatigue test applied to synthetic pump parts have been carried out by:
- WAVIN (dutch synthetics manufacturer), as part of the development of the direct drive 'WAVIN-pump',
- The Department of Engineering, Reading University.

No publications were issued.

2.3 RECENT TECHNICAL RESEARCH ON PISTON PUMPS

(Publications issued)

1. Valves:
   - analytical model for disc valve behaviour: [3.5, CWD]
   - disc valve experiments: [3.5, CWD], [4.3, Yau, G.S.]
2. Piston/cylinder assembly:
   - leather and synthetic piston seals: [6, Hahn, R]
   - synthetic pistons and valves: [2.3, Mills, K.J.]
3. Pump rod to crank connection:
   - endurance test of chains and reinforced rubber band: [6.1, Hahn, R]
   - shock absorber tests: [2.4, CATR]
4. Synthetic rods:
   - experiments by CATR: [2.3, CATR]
5. Riser couplings:
   - threaded coupling parts, limed with epoxy to the PVC riser tubes: [9, WAVIN]
6. Riser suspension:
   - tests applied to Afridev rubber suspension: [2.4, CATR]
7. Pump stand bearings:
   - endurance tests of dry plastic bush assemblies e.o.: [2.2, CATR]

3. CONCLUSIONS

The research of dynamic behaviour, occuring stress and fatigue of handpumps has been confined to:
- empirical research: particularly endurance testing and field trials, of which results have hardly been published, with the exception of CATR and WB projects.
- Theoretical research: University of Malaya and CWD.

The influence of elasticity of the riser (axial and radial) were not included in the research by CWD and the University of Malaya. And hardly the elasticity of the rod. Most likely, due to the restricted realised lifts (8 metre). Research was limited to mechanically driven pumps.

Detailed tests were applied to the dynamic behaviour of disc valves. Most handpumps are, however, equipped with wing valves and these have probably been tested by the manufacturers only. (Not published).

Hardly any research was applied to pumps with free hanging risers and cylinders (as is usually the case in practice!), and with actual lifts of more then 10 metres. Also, the plastic elongation (particularly 'creep' of the riser) has hardly been studied.

Analytical modelling was aimed at a 'dynamic stiff-approuch' with regard to tensions at the pump rod. Part of this configuration is that the pump rod and watercolumn are presented as parts of a spring-mass-dashpot system (massless spring!). Here the respons is calculated on an external subjected harmonic force and movement! This approach is probably too rough for predicting stress and dynamic behaviour, for handoperated handle pumps at larger lifts. (Maybe well in the case of a flywheel pump?). This is due to the neglection/underestimation of:
- the mass-influence of the pump rod,
- the influence of velocity of propagation of pressure waves in the rod , the water column (especially with synthetic risers!), and the riser,
- the elasticity of the riser, in axial and radial direction,

and due to the complex (non-)harmonic movement of the handle, caused by the interaction pump/user.

Detailed information regarding the occuring stress in the pump and fatigue resistance, especially of synthetic parts, is lacking. Therefore, for the present, reliable predictions concerning the life of the pump parts on the basis of analytical models cannot be given.

The goal of the firts phase of the IAD Handpump project, namely, aimed at measuring and analysing dynamic behaviour of hand-operated piston pumps, installed on a borehole, obviously is a good choice. This study can enlarge the insight of dynamic behaviour, resulting stress and its performing factors.

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