The Use of Pedal Power for Agriculture and Transport in Developing Countries

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The use of pedal power for agriculture and transport in developing countries

Report for ITDG Transport Panel

D. Weightman
May 1976

This report examines the existing and potential applications of pedal power for simple agricultural machinery and transport devices in developing countries. A comparison is made between pedal power and other power sources in these applications and figures for human power outputs by various methods are produced to justify the efficiency of pedal power. The appropriateness of the technology involved in this method for the rural poor in developing countries is also discussed.

Contents

Report by David Weightman
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May 1976

1. Power Sources and agricultural development

1.1 There are many factors affecting agricultural productivity in developing countries and it would be simplistic to assume that the solution to problems of low productivity is purely one of applying the right technology. However, there is little doubt that the application of technology constitutes part of the solution.

1.2 Although generalisations are somewhat risky, it can be stated that indigenous methods of agriculture in developing countries rely heavily on the use of human and animal power for the majority of agricultural processing and related transport tasks. These resources are commonly employed with primitive tools which are simple but usually inefficient.

1.3 Experience in agricultural development programmes over the last 30 years has shown that the partial introduction of high capital cost/labour saving machinery, imported from industrialised countries, does not necessarily provide a satisfactory solution to the problems of low agricultural productivity. High cost in foreign exchange, lack of maintenance and spares facilities and an absence of suitable financing arrangements for the poorer farmers have also led to disproportionately greater benefits from such programmes being derived by a small section of the farming community.

1.4 There is a growing realisation, both in the developed and developing world that an "Intermediate Technology", based on increasing the productivity of labour intensive methods by simple, low cost, locally made machinery, offers the best prospects for improving conditions for the rural poor (1) on a 'self-help' basis.

1.5 Machinery of this type for agricultural processing has been developed indigenously in various parts of the world, notably India and China where this philosophy can be traced back to the writings of Gandhi and Mao-tse-tung. In recent years, such machines have been introduced in development programmes by a number of governments (Tanzania, Chile) or aid agencies (ITDG, Oxfam, VITA). The Intermediate Technology development group (ITDG) has produced a catalogue, now in its second edition, of available machines of this type.

1.6 The use of IT machinery has several advantages, not least of which is that the use of labour intensive methods can alleviate rural under employment and contain migration to the urban areas. Also simple, locally made machines can be more extensively used to benefit a wider population and develop small-scale industrial infra-structure.

1.7 In the area of transport, which is closely related to agricultural production, this approach, based on the improvement of labour intensive methods, can increase access to transport facilities by the design of appropriate low cost vehicles.

2. Comparison of available power sources for IT machinery.

2.1 The means of powering IT machinery commonly used are human and animal power electric motors (DC or AC mains) and internal combustion engines using oil based fuels. Other methods which have been used either directly or via an energy storage medium are windpower, water power, solar energy transducers or bio-gas engines. The suitability of a particular method in a given situation will be determined by local environmental, economic and technical conditions but there are generally applicable considerations which can be used as a basis for comparison. Such a comparison will not indicate a single method for universal application but can be used to establish the relative usefulness of human muscle power methods.

2.2 The suitability of a particular type of power source is determined by the following (taken from a report by Alex Weir, University of Dar es Salaam). (2)

2.2.1 Simplicity of operation, maintenance and repair
2.2.2 Cost, both capital and running
2.2.3 For some field applications, portability
2.2.4 Capability for indigenous manufacture with minimal foreign exchange component

2.3 The use of draught animals to power machinery is common in many parts of the world. Although these methods can satisfy all the criteria in 2.2, applications are restricted to those requiring high torque and power at low speeds. The most common arrangement is for the animals to be driven round a capstan, using a gear in the centre to give a higher rotational speed suitable for machine operation. This arrangement is only really suitable for large static machinery such as high capacity pumps and mills.

2.4 Many methods have been employed to use human muscle power - hand cranking being the simplest and most frequently used. As will be seen from the ergonomic date in section 3, the power outputs obtainable from handcranking are between 30-50% lower than methods using the leg muscles and fall further with operating times above 20 minutes. It is, however, the simplest method of operating machinery requiring little power to operate. For heavier machinery and higher powers it is necessary to use the leg muscles which are more powerful than those of the arms. Both treadle and pedal actions are used to drive machinery. The treadle action is commonly operated by one leg, only using half the available power, but enabling the operator to support himself on the other leg and load the machine. Treadle mechanisms are commonly inefficient and much higher power outputs are obtained from the pedal crank arrangement. The operator's freedom of movement is more restricted so machine loading and adjusting tasks have to be arranged to be convenient from his fixed position. This limitation rules out pedal drive for machines like lathes, potters wheels and sewing machines requiring steady positioning.

For most agricultural processing machinery which requires only periodic loading pedaldrive is eminently suitable and indeed has been used in a variety of such machines. The power output available from pedal crank systems in static applications will be about 75 watts (details in section 3 below)

The technology involved in these methods using muscle power is relatively simple and can be simpler in most cases than bicycle technology. The "fuel" used is food calories and the relative costs of power derived from food in this way can be comparable with other methods. It is obviously of paramount importance that methods used should be efficient because of the pyschological effect on the operator. For this reason, the use of pedal drive is likely to be of the best alternative where high outputs are expected.

2.5 Electric motors operated from AC mains supply are probably the best conventional answer, fulfilling 2.2.1 and 2.2.2 satisfactorily. However, use in field and village situations depends on the existence of mains electricification schemes. Although in many countries, the extent of electrification has increased in recent years, it is going to take a long time and large capital investment before the widespread use of electric motors in rural areas becomes possible. The technology of motor manufacture is also relatively complex and outside the present capabilities of many developing countries. Recent developments in methods of manufacturing motors may result in lower costs but at present, these methods (printed motors, permanent magnet motors etc.) can only be used in developed industrial countries. Also large scale mains electrification depends on fossil fuel or nuclear power stations for initial energy production with obvious problems for countries not rich in these resources.

2.6 DC electric motors operated from accumulators can be used and could satisfy the first three criteria in 2.2. Local manufacturing problems would be similar to those mentioned in 2.5. Providing the accumulators are recharged from small scale "income" energy resources such as wind or hydro-electric generators, then the problems of costs etc. discussed above could be overcome. The suitability of either of these two sources will be dependent on local conditions. Certainly, wind driven generators could provide an attractive, low cost solution, overcoming some of the problems of inefficiency in energy storage by reducing fuel costs to zero.

Recent developments (in UK) of permanent magnet motors with a claimed efficiency of 90%, requiring smaller accumulators may also provide an answer in future. These advantages may be offset by the more complex manufacturing techniques and the electronic speed control used in these motors. To date, a 500w motors for propelling a bicycle has been designed and a range of larger motirs is envisaged.

2.7 The use of solar energy at present is confined to the production of heat, this being the simplest thing to do directly. Generation of electricity from solar energy by photo-voltaic cells is at present not comparable in cost with other methods although this may change. More convenient is the use of solar energy indirectly for the growing of food or plant matter for methane generators.

2.8 Methane (biogas) generation in small scale plants is currently being investigated as a technique for energy production suitable for developing countries. The costs of energy produced in this way can be comparable to conventional sources (coal, hydro-electric, etc.) with the advantage of the use of plant matter or manure as fuel for machine operation, conventional internal combustion engines, suitably converted, can be used. This method is most convenient when the engine can be fed directly from the methane generator because of the problems of storing and transporting the gas so applications are likely to be restricted by this limitation.

2.9 Apart from electricity generation, wind power can and has been used to drive static machinery such as pumps and mills. The efficiency of windmills is increased by building high towers so that static applications are the most appropriate way to use windpower effectively.

2.10 Internal combustion engines have been conventionally assumed to be the best portable power source for agricultural machinery requiring higher powers. The high energy storage density of petrol or diesel fuel and the compactness of engines are very potent factors. Apart from the fact that manufacturing and maintaining engines involves a high level of technical expertise, the main challenge to this assumption comes from the availability and cost of the fuel. For those countries with no indigenous supplies of oil, competition for oil in the world market is difficult and likely to become more so. This will affect most severely those countries without deposits of other valuable raw materials. In this situation, investigation of alternatives to oil fuelled IC engines is of considerably more importance to the poorest nations. Also, in view of the particular suitability of oil fuelled engines for transport applications where the high energy storage density of petrol is hard to better, then it is best to consider in the long term, the use of alternative power sources for static machine applications. Although some work has been done in investigating alternative fuels for IC engines (methanol, ethanol), a lot more needs to be done to demonstrate the viability of these alternatives.

2.11 A cost comparison between different energy sources in capital and fuel costs has been carried out by Alex Weir (3). Although any such comparison is likely to be affected greatly by local economic and technical factors and any results will not be universal, this study, done in Uganda in 1972 provides some basis for evaluating different methods. Mr. Weir was working at the time on the design of a 'dynapod', s static frame comprising saddle and pedal system with a power take-off for machinery.

	Power kw	Costs in US dollars (1972 prices)		
		Capital cost	Capital cost/ kw	Fuel cost/ kw
1 man dynapod	0.1	25	250	0.05
Electric motor A	0.175	33-66	180-380	0.04
Electric motor B	0.375	39-78	104-208	0.04
Diesel engine	3.75	471	126	0.04

Fuels-dynapod, maize flour 0.17S kg, 4kcal/gm
electric, unit 0.018S, motor 50% efficient
diesel, 0.16 S 1 litre, 20,000 BTU/lb,
engine 25% efficient

(source reference 2)

2.12 This comparison does not take into account the cost of electrification or of maintenance, both factors which would affect the costs for electric motors and diesel engines. In the absence of a rural electrification scheme or an infrastructure for maintaining IC engines,it is likely that the use of pedal power would constitute a valuable alternative to the other methods. As discussed above, the fuel costs for the other sources may be imported and therefore dependent on world market fluctuations. Certainly the fuel costs for diesel engines given at 1972 prices could now be doubled, at least. Other power source costs (windmills, biogas engines etc.) have not been calculated as yet but the differences are not likely to be significant. The factors affecting suitability of different power sources are as much dependent on compatibility with the indigenous level of technology as on straightforward fuel costs.

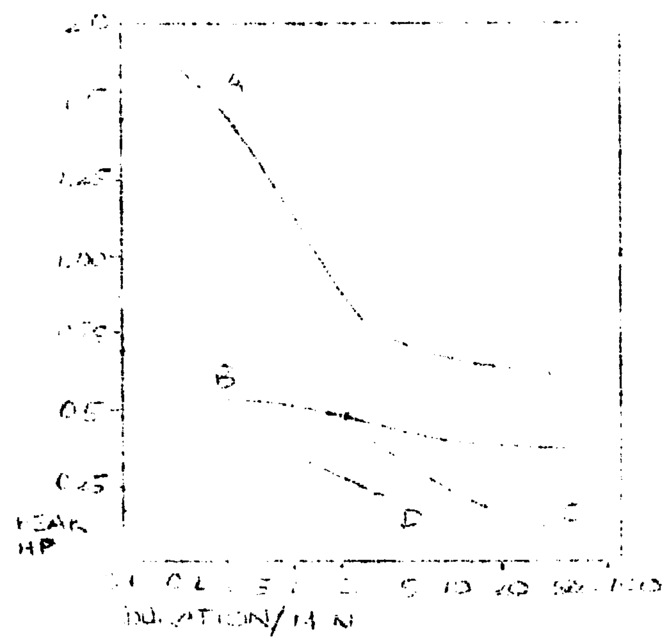
2.13 In conclusion, pedal power can be comparable with other methods but has particular utility because of the relatively simple technology involved. The majority of farmers in developing countries at present consume comparatively small amounts of energy by inefficient methods. Because pedal powered equipment is smallscale and cheap, this can improve the situation. The low cost makes individual ownership of power sources more feasible and the simplicity of the technology can foster development of technical skills amongst farmers themselves.

3. Pedal Power Ergonomics

3.1 The data in this section is drawn largely from the book 'Bicycling Science' by Frank Whitt and David Wilson. This book is the definitive analysis of the ergonomics and mechanics of bicycles and constitutes an invaluable reference for work in this area.

3.2 Muscle power output arises from the conversion of food calories by oxygen so is limited by nutrition levels and oxygen intake. General fitness or training results in a higher efficiency of oxygen conversion and hence greater power outputs. As would be expects, outputs vary with the muscle groups employed and with duration, higher outputs being obtained over shorter periods. Figure 1 (4) shows this relationship and also provides a comparison between different muscle groups.

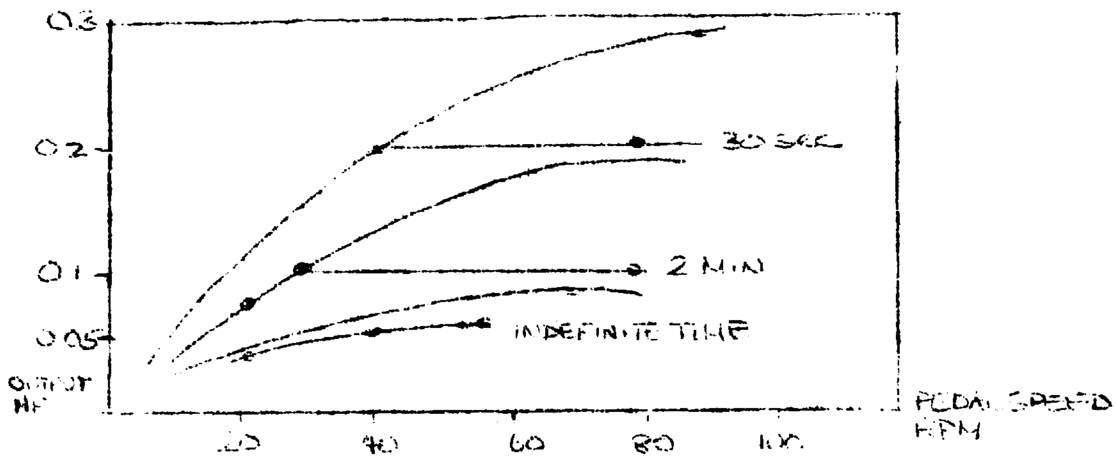
Figure 1. Output/time



A Racing cyclist
B Pedal Ergometer
C Winch
D Hand Ergometer

3.3 It can be seen from this that the outputs obtainable from hand cranking are approximately 30% or less than that measured from cyclists and on average 50% less than measured on pedal driven ergometers. The difference between ergometer measurements and cyclists performance occurs because of the effect on windflow in reducing the rise in body temperature resulting from muscular activity. This indicates that for static application of pedal power provision of cooling fans may be advantageous. These figures, however, were measured from athletes performances and should not be taken as average. It has long been assumed that an average bicyclist produces 0.1 HP (75 watts) which would give a road speed of 9-13 mph (4-5.8 m/sec) and this accords with accurate measurement and observation. Figure 2 shows the variation of output with time for american college students (5) and indicates for general purposes over long times (20 mins or so) that this output can reasonably be expected. This output is obtained using about 50% of maximum breathing capacity.

Figure 2. Power output/time/pedal speed



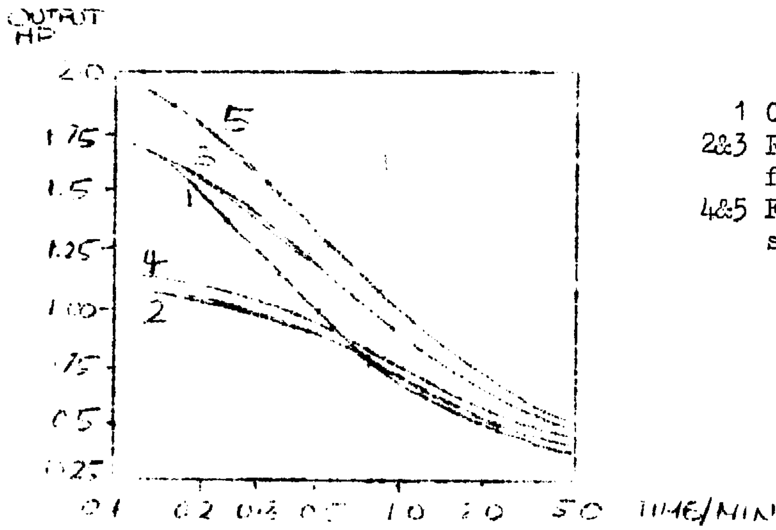
3.4 This figure shows how output varies with pedal speed and that for low outputs a variation of pedal speeds between 30-60 rpm have little effect. For racing cyclists producing higher outputs, the effect of pedal crank speed is more critical and crank speeds up to 150-180 rpm are used. For high outputs the optimum has been suggested by the Japanese Bicycle Research Association (6) to be 70 rpm using much higher gears than usual for racing cyclists. The optimum crank length was determined to be $6\frac{3}{4}$" (170mm) which accords with practise.

3.5 Tests on ergometers (7) have shown that pedalling in a near horizontal position is only about 80% as effective, in terms of muscle usage, than the normal upright position. Over long periods, pedallers complained of 'knee strain' when pedalling sitting down. In spite of this, records have been made, particularly in the 1930's, on recumbent bicycles, but only for short distances. This is probably due to slightly higher outputs being obtained by the seat back counteracting pedal thrusts rather than the arm trunk muscles, and also due to lower wind resistance.

3.6 Comparisons of walking up gradients (9), stepping up and down and pedalling, indicate that the usage of oxygen for a given power output is similar. This means that there is no gain in efficiency from lever systems which use leg motions other than pedalling. There may well be increased losses with 'stepping' actions due to mechanical inefficiency of the transduring system. Indeed for most applications, the pedal and crank system which gives a smooth rotary motion initially is likely to be most useful.

Rowing actions have been tested by Harrison (8) and in these studies it was found that higher outputs than those obtained by pedaller could be produced, particularly if the rowing action was connected to a mechanism which defined the end of the stroke (forced action). Outputs against time are shown in figure 3 and this indicates that the rowing action becomes less advantageous with times over 5 minutes.

F Figure 3. Rowing versus pedalling actions (5)



1 Cycling
2&3 Free and forced rowing, feet fixed
4&5 Free and forced rowing, seat fixed

3.8 The general conclusion of these comparisons is that for applications both in vehicles and for driving machines, the normal pedal and crank action is best suited for general use over periods greater than 5 minutes or so. For shorter times, where higher outputs are necessary, it may be better to use a recumbent pedalling position or a rowing action. Outputs of 0.1 HP (7 (75 watts) are produced by normal cyclists for reasonable times, but lower outputs are obviously more easily maintained. It is difficult to predict how these outputs would be modified by lower nutrition levels prevalent in developing countries but figures of 0.05-0.08 HP (37.3-59.7 watts) could be relied on.

3.9 For static machine applications, the appropriate gearing may not be the same as the ratios used on bicycles. This is commonly a 46 tooth front and 18 tooth rear sprocket for single speed bicycles. With the optimum pedal crank rotation speed of 70 rpm, this would give a reas spocket speed of 180 rpm. In determining gear ratios for other machinery it is worthwhile assuming a pedal crank rotation speed of 70 rpm and design accordingly.

3.10 As shown below the optimum position for pedalling over a period is the conventional upright position used on bicycles. The variations in seat tube angle and handlebar type over the standard bicycle found on bicycles designed for racing arise the necessity to reduce wind resistance and minimise shock to the spine at high high speeds more than to gain an improvement in output. The overall geometry of the standard bicycle should therefore be followed in the construction of pedal driven devices.

4. Existing or possible machinery and designs using pedal power or suitable for conversion.

Main source of information is ITDG "Tools for Agriculture - guide to hand-operated, animal drawn and small engine powered equipment" 2nd edition, ITDG Publications 1976.

Numbers refer to codes used in Catalogue, with country of origin.
Short number codes refer to page numbers in "Tools for Agriculture" ITDG, 1st edition.
Initials refer to designers or sources of information
SW - Stuart Wilson, Department of Engineering Science, Oxford University
AW - University of Dares-Salaam
WE - ITDG Workshop
RM - Robert Mann, NCAE, Silsoe

Machine Type	Machines using pedal drive	Machines suitable for conversion (and drive method used) at present
4.1 Agriculture		
Pumps	Automatic pump (SW) Chinese Dragon tooth pump (SW)	Climax (UK.053H.01) hand Godwin (UK.053H.05) hand Howl (053H.13) hand Cossul (India,053H.03) 2 man, hand
Maize Shellers	Hunts Cobmaster (UK 071H1.09)	Allied (071H1.01) hand CeCoCo (Japan 071H1.02) hand Cossul (India 071H1.03) hand Hunts Atlas (UK 071H1.05) hand Alvan Blanch (UK,073.07) hand
Rotary Cleaners		Siscoma (Senegal,073.08) hand

Grinding Mills	Atlas Mini Mill(SW)	CeCoCo (Japan 091H.01) hand Gaubert (France 091H.02) hand Diamant (Denmark 091H.03) hand Atlas (UK 091H.04) hand Dunia (Kenya 091H.06) hand Amuda (India 091P.09) ½ hp electric motor
Corn Crushers		Renson & Cie(France 091H. 06) hand
Cereal Breaker		CeCoCo (Japan 095.01) hand
Chaff Cutter		Dandekar (India 092.04) hand Hunts (UK 092.05) hand Johnson Silex (South Africa 092.06) hand Ajantz (India 092.08) hand Rajasthan (India 092.09) hand Mohunder (India 071H1.04) Renson & Cie (France 071P1. 07) ½ HP electric motor
Groundnut decorticators		Dandekar (India 071H2.01) hand Hudsons (India 071H2.03) foot treadle Siscoma (Senegal 071H2.06) hand
Threshers	Akshat (India 07H3.01) Cossul (India 071H3.03) Aplos (55) Doring (Germany, 63) VITA design Malayan design(RM)	CeCoCo (Japan 071H3.02) Foot treadle Midget (56) Cossul (India 62)

Winnowing fans	Akshat (India 07H3.01) Cossul (India 071H3.03)	
Winnowing machines	NCAE design (RM)	CeCoCo (Japan 073.01) hand Hudsons (India 073.02) ½ HP electric motor Hunts (UK 073.03) hand Rajasthan (India 073.04) hand Renson & Cie (France 092.12) hand
Rootcutters		CeCoCo (Japam 092.03) hand or motor Renson & Cie (France 092.11) electric motor
Coffee Hullers		Gordon (UK 094.08) hand
Coffee pulpers		Bentall (UK 094.02) hand Gordon (UK)(094.12) hand & (094.06) hand McKinnon (UK 094.12) hand and (094.13) hand
Palm nut crackers		Harrap Wilkinson (UK 094.01) hand Voms (65) Rapid (66)
Rice Hullers		CeCoCo (Japan 094.01) hand, 2 man Gordon (UK 094.04) hand
Rice polishers		CeCoCo (Japan 094.03) hand

Cane squeezers		CeCoCo (Japan 094.01) hand
Cassava graters	ITDG design (WE)	
Banana fibre pulper		
Riddler		
Shearer		
Winchplough	French design (SW)	
Grain elevator		

4.2 Industrial machines

Electrical generator	Design (SW)using bicycle and alternator	
Winch	Design (SW)	
Forgeblower	Zambian design (ITDG)	
Air compressor		
Bandsaw		
Fretsaw		
Lathe		
Pillardrill		
Grindstone		

5. Methods of using Pedal Power to drive machinery

5.1 A number of different methods have been proposed or used in various applications. These methods fall into four categories - converted bicycles; pedal drives fitted to machine; dynapods and pedal power units (PPU's). The suitability of each method will be determined by the machine type and pattern of usage. Social and economic factors will also affect the use patterns, with the classification of work tasks and the local financing system playing some part in the selection of an appropriate method.

5.2 The design of bicycle commonly available in developing is little different from the original 'Safety' bicycle first designed in the 1890's. Whilst it is an admirable device for personal transport and is commonly used in developing countries to transport large loads or passengers, it has not been designed as a power source for machinery. In spite of this, use has been made of bicycles to drive machines as availability makes this dual use attractive. Unless the bicycle is cannabalised, and therefore loses its transport function, methods of adaptation inevitably involve some compromise. If this potential dual use was taken into account in the initial design stage by manufacturers, along with the use of construction methods more suited to the available technology then a vehicle more appropriate to the needs of people in developing countries would result.

5.3 Conventional bicycles are used to drive machines in three ways. The first, and simplest, is by a friction roller driven by the rear wheel, with the bicycle clamping on a stand. Whilst not particularly efficient, this method gives a high speed power takeoff, commonly 2000 rpm, but dependant on roller diameter. Power take-off at this speed is most suitable for electricity generation or for driving simple fans for winnowing. A design for a generator has been produced by students at Edinburgh University (12) with a power output of electrical watts. Cossul of India produce a winnowing fan to clamp onto the rear carrier of a bicycle, driven by a roller pressing on the rear wheel. An ex-GI working in Vietnam has designed and tested a centrifrugal tube pump for paddy irrigation driven in this way. Although designs have been produced for an universal power source using this method (13), it is unlikely to be suitable for uses other than the three mentioned above. This is because of the high rpm power takeoff is only applicable in cases like these. For these uses, however, this method is very simple and can be used with little modification to the bicycle. The stand designed by the Edinburgh students is an excellent example of design for low technology and no doubt a better design for a drop-down rear carrier incorporating a roller could be produced than that evolved by Professor Papaneks student group.

5.4 The second method used is to replace the rear wheel with a pulley with a belt drive taken to the machine. Apart from the problems of removing and replacing the rear wheel and clamping the bicycle firmly, this method has the disadvantage that the drive is taken from behind the operator. This is not the optimum arrangement as the operator cannot see the results of his labour, important for pyschological reasons, and also the operator cannot load or monitor the machine. It is more appropriatefor longer machine use times because of the time taken for initial setting up. It has also been discovered in some situations that there is resistance on the part of peasants to use their bicycles in this way although this may not be generally the case, it is worth acknowledging the value that people may attach to their personal transport vehicles in the same way, car owners in Europe might resist suggestions that they could use their vehicles to drive cement mixers. In general, therefore, this method is likely to be more appropriate for machines operated as workplaces for the working day.

5.5 The third method is to take a secondary chain drive from the pedal sprocket to a layshaft mounted on the steering head of the bicycle. This chain would normally be driven all the time and so reduce the bicycles use as a multi-passenger vehicle. The drive is taken forward with advantages for machine operation. This method has been seen occasionally in use in India by the author and may have a wider application than at present. It involves some compromise as use as a vehicle or as a power source means that an extra chain system is being moved to no purpose in each case.

5.6 The use of conventional bicycles by any of the methods described above involves compromise but can be useful for particular applications.

5.7 It can be seen from the table in section 4 above, that a number of machines have been designed or produced fitted with pedal drive. There is little doubt that this is the mest method for any particular machine as the arrangement can be optimised for that application. It also allows the use of chain drive systems for high efficiency. Bicycle components are commonly used in such designs because of availability and the high quality of bearings and cranks etc., but in some cases, where cost is important, simpler locally made components have been used. In particular, oil impregnated wooden block bearings have been used as a substitute for ball bearings with some loss in efficiency. If old bicycles are available at suitable cost these can be cannibalised for parts or for incorporation into machine designs but bicycles have a much longer useful life as vehicles in developing countries than is commonly assumed.

5.8 Incorporating pedal drive into machine involves the provision of a pedal axle, saddle and handlebars with some measure of adjustment for the latter two to suit different sizes of user.

5.9 Although direct incorporation of the drive into machine can give optimum efficiency, whether this is the best method depends on the use situation. It is most suitable for machines which are in constant use, either by a single farmer or by members of a community.

5.10 Where a range of machines are used, it may be more economic to have a detachable drive system able to be transferred between machines. This can result in some cost savings over fixed pedal drive on each machine.

5.11 This flexibility is the basis of the Dynapod concept evolved by Stuart Wilson of Oxford University (14). A dynapod is a frame comprising a saddle and pedal drive with a number of power takeoffs for connection to machines. In the initial proposal described in reference 14 , the drive chain was connected to two layshafts, giving two speed takeoffs. Connection to the driven machine was by belt or by flexible shaft and Stuart Wilson suggests the use of bamboo or GRP for this shaft to reduce costs and minimise alignment problems.

5.12 Since the publication of the initial proposal in 1968, Alex Weir, working in Uganda and Tanzania has built and tested a number of one or two man dynapods. These were locally constructed from timber or stock steel sections and some used a flywheel made by casting concrete onto an old bicycle wheel. Experience with these indicated some important points for future developments. In particular it is vital to provide a strut between chain sprockets or belt pulleys to maintain tension and alleviate chain or belt jumping under load. Also the savings in cost achieved by the use of crudely fabricated pedal crankshafts were sometimes lost by reduced reliability.

5.13 Although an optimum design for a dynapod has yet to be developed, work to date has indicated that the concept has merit where a range of machines are to be driven. This means that it is a feasible proposition if owned and operated as a communal power source or in cases where a single farmer can put it to constant use in a number of applications.

5.14 The pedal power unit (PPU) was developed by the author from the basic dynapod. This development is described more fully in a report (15). The rationale for the PPU arose from consideration of how the machine uses of pedal power relate to potential transport uses. The pedal power unit comprises a pedalled road wheel in forks fitted to a frame with saddle. This unit can be used independently to drive machinery via a power take off and can be connected to a two-wheel chassis to form a load carrying tricycle. The unit can also be connected in series with other units for machine applications requiring higher powers.

5.15 The link between transport and machine uses can be seen in studying agricultural or industrial production. In a typical agricultural growing cycle, seed and fertiliser are transported to the field, crops are grown and processed by IT Machinery then produce is transported to market. Similar patterns can be seen in construction or small scale industrial production. The use of a pedal power unit in this dual purpose role is exactly analagous to the use of tractors in European agriculture as power sources and transport devices.

5.16 The PPU is intended to extend the utility of transport and further work is currently being undertaken by the author to develop the design and evaluate its feasability. In terms of uses, the PPU would suit the same pattern of usage as the dynapod (5.13) but with the benefit of this additional use to amortise cost more quickly.

5.17 To summarise the methods of use described above:-

5.17.1 The utility of bicycles is limited to a number of specific applications such as electircity generation, winnowing fans and certain types of pump, due to the problems of adaptation.

5.17.2 If the potential use of the bicycle as a power source was taken into account at the initial design stage, then this dual use could be accommodated satisfactorily as well as other design changes to enable local manufacture.

5.17.3 Fitting pedal drive directly to the machine enables optimisation in that particular application and is most suitable for machines which are in constant use or communally owned or hired.

5.17.4 The dynapod is a feasible solution for communal ownership when a number of machines can be operated in turn, or for a farmer with a range of machines.

5.17.5 The PPU is equally suitable when operating a number of machines but is more economically feasible for an individual farmer due to its capability as a transport device.

6. Pedal Power and transport

6.1 It is justifiable to consider transport in this context as most agricultural activities have related transport activity. This section will concentrate on the role of pedal power in transport and although there are many parts of the world, primarily in Asia, where pedal powered vehicles are common, in other areas they are virtually unused apart from bicycles. This could form the basis for a transfer of technology where appropriate.

6.2 The unsuitability of the standard bicycle type commonly found in developing countries for powering machinery has been referred to above (section 5). As this bicycle type was designed primarily for personal transport, it is also not suitable for the load carrying tasks (either loads or extra passengers) for which it is commonly employed. Loads of 50kg are frequently carried on bicycles with great skill but at high risk.

6.3 The simplest solution to the problem of carrying loads by bicycle is to use a trailer hauled behind and hitched by a moveable coupling to the saddle post. These trailers, using bicycle wheels, are simple to construct and can carry loads of up to 100kg.

6.4 Carrier bicycles as used in the UK and Europe have a small front wheel with a large load basket above. These can be quite effective but loads are limited to 50kg at most and rough road performance is impaired.

6.5 Bicycles have been produced in the UK for improved load carriage using smaller wheels (down to 16"/40 cm diameter) to achieve a lower centre of gravity but again loads are limited to around 50kg. This could be considered if an appropriate bicycle design was being evolved for developing countries.

6.6 A bicycle transporter has been produced in Mozambique (16) based by converting a bicycle into a 2 wheel load carrier. Although loads of up to kg can be carried on this, the original transport function of the bicycle is lost. A more effective solution, employed by the North Vietnamese to move loads down the Ho-Chi-Minh trail, is to strap loads in 'saddlebags' to an ordinary bicycle on a temporary basis and similar loads can be moved without destroying the bicycle.

6.7 The next stage up is the tricycle configuration and two main types exist. The first, found in Mexico, Calcutta, Amsterdam, Indonesia etc. has a two wheel bogey at the front, coupled to a standard bicycle frame at the rear with a modified steering head. Usually the bogy is pivoted at the centre of the front axle and steering is achieved by moving the load box directly. This configuration simplifies the problem of drive but steering tends to be very heavy and difficult, rendering it suitable only for good road surfaces.

6.8 A more effective arrangement is to have two driven wheels at the rear and this configuration is commonly found in India and China. Considerable variation in design is found as attempts to overcome the problems of construction, rear wheel drive and braking have been made. The traditional Indian rickshaw, for example, has a solid rear axle, making cornering difficult and limiting the track. Also a single gear, usually the same ratio as used on a bicycle, is employed with obvious problems when moving heavy loads. No freewheel is used in the chain system and although this gives a reverse gear and some braking action for the rear wheels through the pedals, this makes operation difficult. Auxiliary rear brakes are commonly not provided.

6.9 In China, a variety of designs is found evolved to overcome some, but usually not all, of these problems. Tricycles with two gears, either by double chain wheels (as on 10 speed European bicycles) or by parallel chain system selectively engaged by dog clutches are in use, designed to provide suitable gear ratios for pedalling under load. Band Brakes, with an operating chain connected to the steering head and applied by foot pressure on this chain are also used.

6.10 Neither the Indian or Chinese types are optimum solutions and also share the disadvantage that standard bicycle frames are used for the chassis. However loads of up to 150kg or two passengers (apart from the driver) are moved by these vehicles.

6.11 An improved tricycle has been designed by Stuart Wilson, called the Oxtrike, as an optimum vehicle to be suitable for local manufacture. This uses a bicycle hub gear box in the chain system with both rear wheels on half axles, driven by a simple differential unit made from two cycle freewheels coupled together. This elegant solution is low cost and apart from giving a differential drive to the rear wheels on cornering, also acts as a limited-slip differential on slippery surfaces. The chassis is designed to be fabricated from folded steel sheet in village workshops and the design uses standard bicycle bearings etc. to simplify manufacture. Loads of up to 200kg or two passengers can be carried.

6.12 Wilson has also designed, but not yet constructed, a pedal driven, 4-man vehicle for off-road use. This uses a large (40"/100cm) wheel directly driven by pedals and carried in forks. The chassis comprises two bogeys, each with two of these wheels, pivoted at the centre of the vehicle. The high ground clearance and large wheels would be suitable for off-road use although the design has yet to be proven. (17)

6.13 A design, being developed by the author and referred to in section 5, is a pedal power unit. The PPU forms the driven front wheel of a load carrying tricycle and a prototype has been built to evaluate its transport performance. As this design is intended for dual-use in transport and machine applications, this indicates the relation of the two roles that pedal power can play. (15)

6.14 In countries where these pedal powered vehicles are used, their utility as intermediate transport vehicles between handcarts and motorised vehicles is adequately demonstrated. If more widely used, the lower speeds and lower axle loadings could enable savings in rural road construction costs to be made (18). The technology involved in the construction of these vehicles can be simpler than that currently employed in bicycle manufacture if this is taken into account at the design stage. Certainly the Chinese transport system, being based on the bicycle, rather than the car or lorry, indicates the particular suitability of pedal power to the transport requirements of developing countries.

7. Conclusions

7.1 The efficient use of human muscle power through pedal drive systems conscitutes a useful alternative to other power sources for agricultural processing machinery in a number of applications.

7.2 Because of the relative simplicity of the technology involved and its potential wide application, the wider use of pedal power could act as a stimulus for small scale industrial development. This would parellel the development of the aircraft, automobile and machine tool industries from the base of the bicycle industry in the UK in the early 20th century.

7.3 Pedal driven vehicles form an intermediate stage between manual or animal drawn vehicles and motorised types and can be seen to perform this role successfully in countries where they are currently in use.

7.4 Future consideration of the 'human-scale' technology involved in these applications could be of great benefit to developing countries and it is maybe no coincidence that this is occurring at the same time as a resurgence of interest in the bicycle as a means of solving the transport problem in urban areas in the industrialised countries of the world.

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