A Variable Stroke Mechanism for Ornithopters

by Peter L. Valentine 5-11-96

In the article entitled 'Flapping Wing Models' (Spring 1987 Flapper Facts), Horst Handler lists a number of 'good things to have' in a mechanism for a powered ornithopter, among which: " A regulatable amount of flapping angle is desireable". I'll call this variable stroke and paraphrase Handler to say it's also good if an ornithopter mechanism can be stopped with the wings held at a certain dihedral angle to allow stable gliding flight.

It's been over ten years since I researched the field of variable stroke mechanisms and I'd like to share what I found with the OMS. Consider the schematic in Fig. 1 with a driving crank, 1, and a driven block, 8 (Ref. 1, pp. 371-372). With the control lever at 0, there is no movement of block 8 at 0'. With the lever at 1, the block cycles between 0' and 1'. With the lever at 2, the block cycles between 0' and 2', and so on. If the block is attached to a wing (or a pair of wings), the crank driven by a geared motor, and the lever moved and held by an actuator, we have all the ingredients of a variable flapping angle ornithopter.

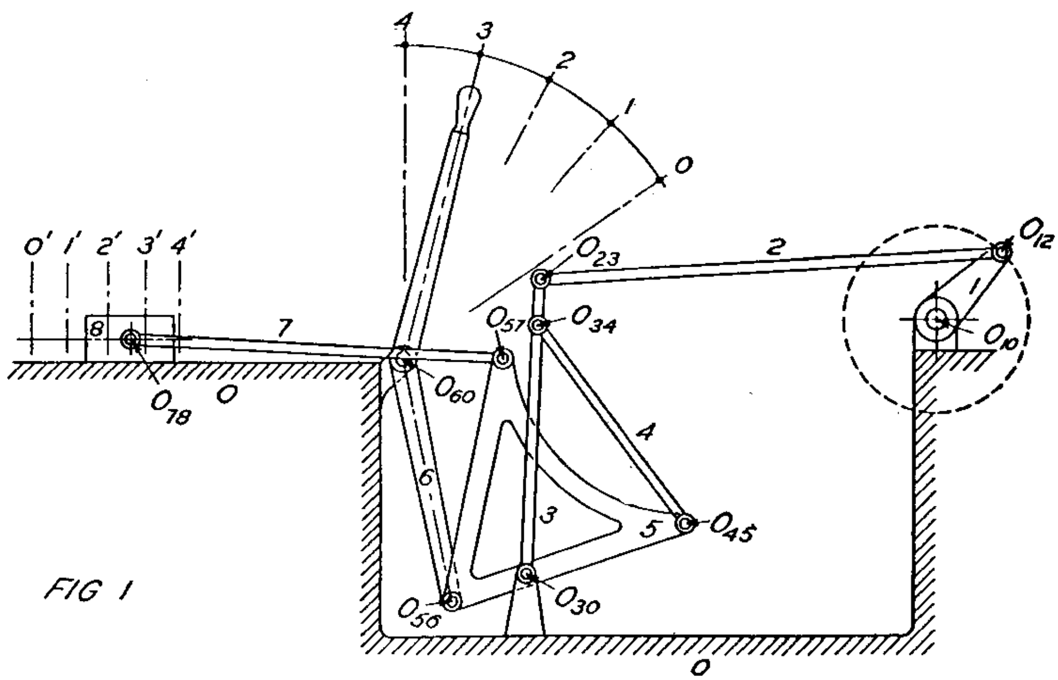

FIG 1

From the description of the operation of the Fig. 1 mechanism it's apparent that the 'mean' stroke angle changes with stroke amplitude. In Fig. 2 I've sketched an ornithopter design where this characteristic is used to give the wings the greatest dihedral angle when the stroke is zero, and this might just be what Handler would want for a stable glide. You'll note I installed stroke control on both wings to provide turning capability as well as thrust control. If I was building models, I might start with one mechanism driving both wings and use rudder and elevator for turns. Another possibility would be to forget about fixed wing gliding, use stroke frequency (motor RPM) as thrust control, use fixed stroke on one side and variable stroke on the other so that more or less stroke amplitude on the controlled side would cause turning one way or the other.

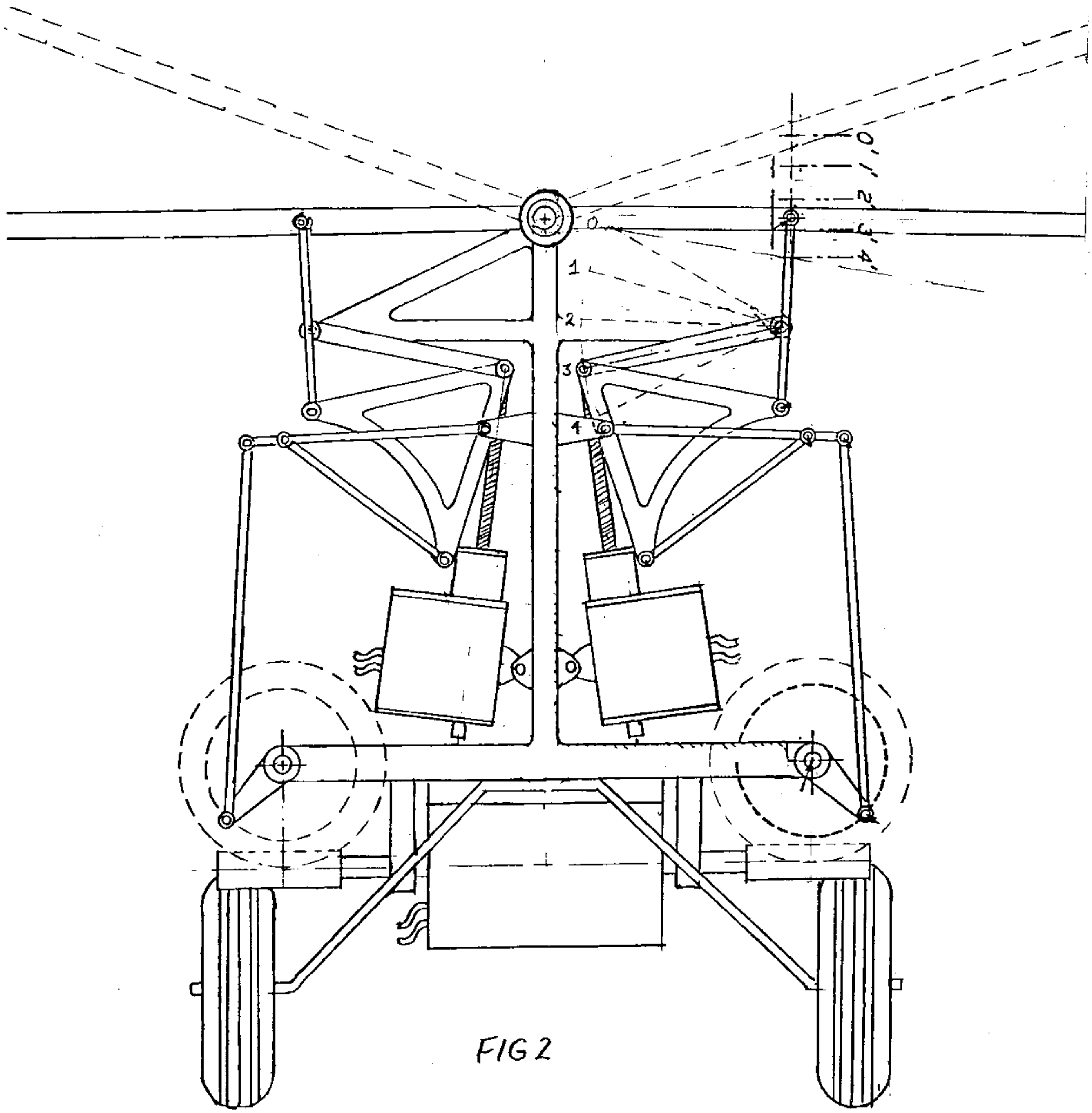

FIG 2

This is all I have to say about ornithopters and stroke control for now. But in case anyone's wondering where this mechanism came from and what, if anything, it is, or was, used for, I thought I'd write some more about what I learned about variable stroke mechanisms. Enjoy.

Variable Stroke Mechanisms from the Age of Steam

Fig 3 shows a simple double acting steam engine with a slider valve driven by an eccentric. An eccentric performs the same function as a crank except that it's designed to be used with an existing circular shaft (by bolting it on in pieces if necessary) as opposed to fabricating a shaft with an extra crank built in. Figure 4 shows that if one eccentric is nested inside another with some kind of key or other method of holding them together, a variable eccentric results. If the eccentricity e is the same for both eccentrics, it is possible to change the stroke from zero to a maximum of 2e as shown . Such devices are used for laboratory fatigue tests to impose an adjustable amount of cyclic deflection, say, on the end of a beam, but they must be stopped and reassembled in order to change the stroke amplitude. Recently, inventors have incorporated helical splines between the nested eccentrics so that differential shaft movement 'in and out of the page' can be used to adjust the stroke 'on the fly', but if fixed eccentrics are never used for serious power transmission because of machining expense and limited torque capacity, variable eccentrics become even more undesirable.

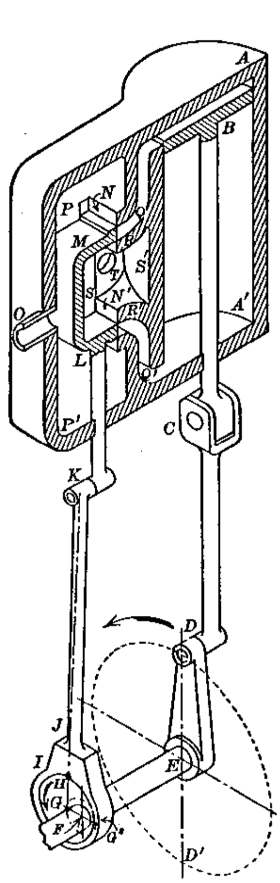

Fig. 3 Simple Steam Engine

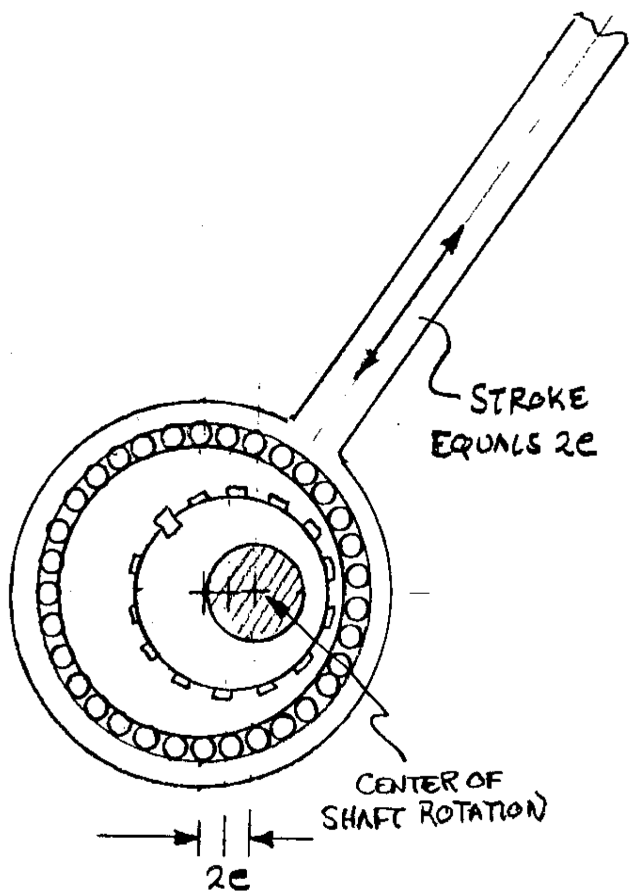

Fig. 4 Variable Eccentric, Stroke from 0 to 2e

Developing a variable stroke device for steam engines is one of the two things needed for control in applications such as rail locomotives (the other is reversing ability) where varying degrees of torque are required and conservation of steam is important. Without such a device, the only way to control the output of the engine in Fig 3 is to throttle the steam and this is wasteful. As we have seen, something like a variable crank or eccentric is needed, but the variable 'on the fly' eccentric described was, in the days of steam (and maybe still is), too difficult to machine and therefore too expensive for the application. Instead, one mechanism that appeared was the Stephenson Valve Gear in Fig 5 (this and the following illustrations from Ref. 2). As is apparent, there are two fixed eccentrics driving the ends of a Link with a curved slot. If the Link is raised up with the Reversing Rod so that the Saddle block is situated on top of the Slide Block, the two ends of the link pivot madly about without producing any stroke in the Valve rod. From here, if the Link is raised, the Valve rod strokes with increasing amplitude 'fore and aft' and if it is lowered, the same thing happens except now the motion is 'aft and forward', that is, in the reverse phase relationship. The variable stroke feature acts as a throttle by allowing more or less pressurized steam onto one side of the piston or the other and the phase change around 'zero stroke' allows the engine to be started and run in one direction or the other. Some of the nicer toy steam engine models were equipped with working valve gear of this type.

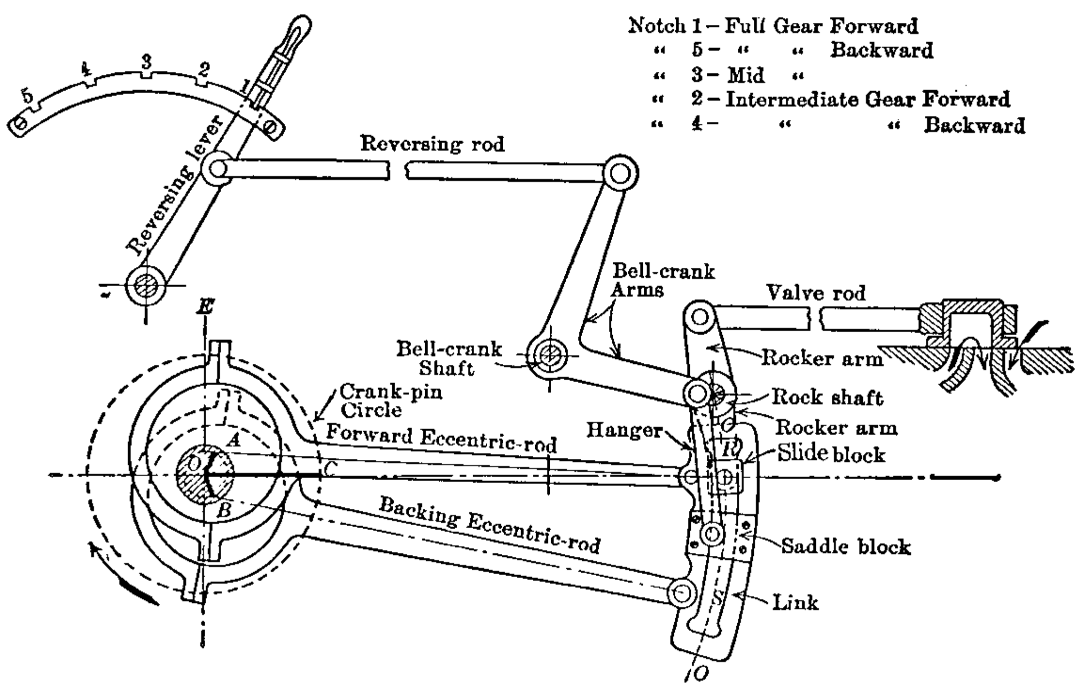

Fig. 5 Stephenson Valve Gear

As the age of steam progressed, numerous valve gear mechanisms were designed to produce precise valve motions while meeting the requirements of specific applications such as compactness, light weight, low cost, easy maintainability, and others. For example, Fig. 6 shows the Gooch Gear which was used in preference to the Stephenson for stationary powerplants. Note that the Stephenson Gear in Fig. 5 needs a notched quadrant in order to hold the reversing rod at a particular position. This is partly due to the reversing lever supporting the weight of the link and a part of the weight of the eccentric rods and partly due

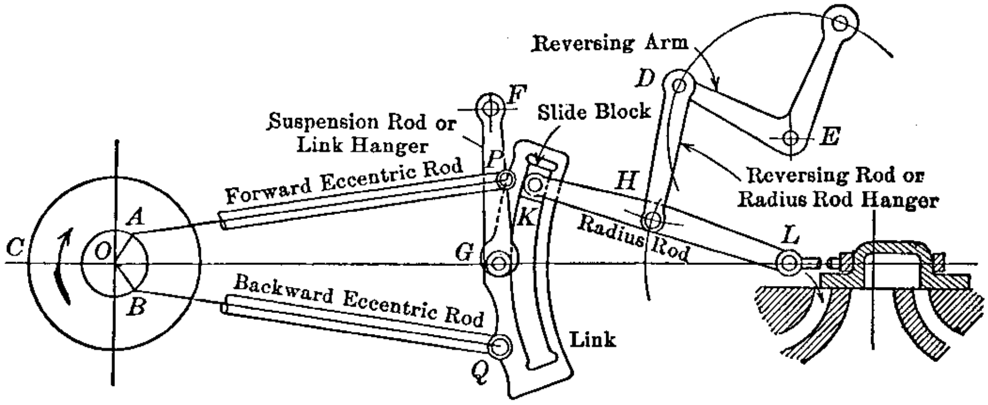

Fig. 6 Gooch Valve Gear

to the dynamic loads experienced when the mechanism is in motion. The Gooch Gear, on the other hand, pins the Link so that only the weight of the Radius Rod is carried by the Reversing Rod, and this makes for a more easily balanced load, which is what is wanted if the engine is to be controlled by a speed governor. As an aside, I've been working with locomotives at GE Erie for that last two years. The throttle quadrants on diesel electric locos still carry numbers to indicate relative power level (1-8) and these are still, always, refered to as 'notch levels'.

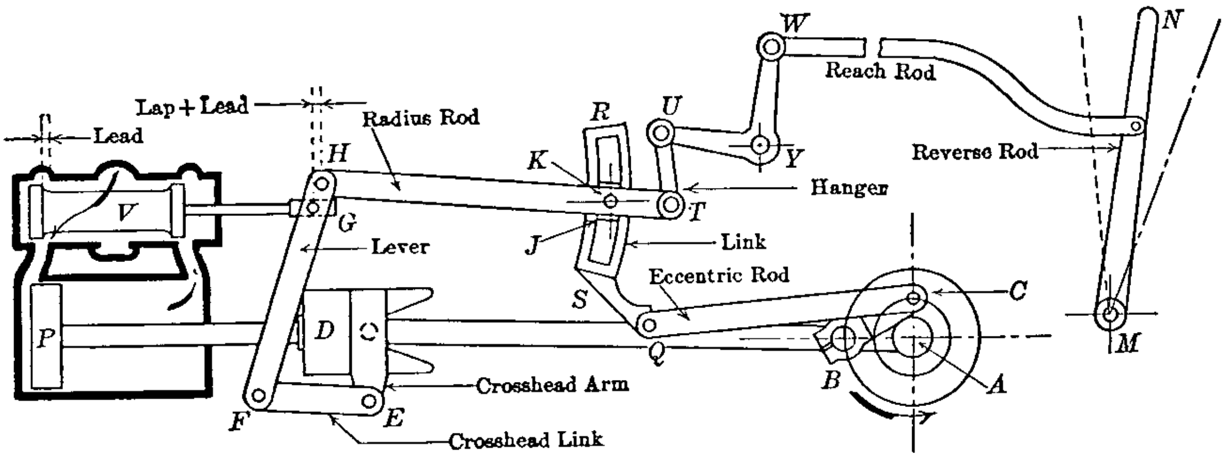

Fig. 7 Walschaert Valve Gear

Two more examples and I'm done. Fig. 7 shows the Walschaert Gear which was used extensively on steam locomotives until they were no longer built. As with the Gooch Gear, the Link is pinned and the Radius Rod is moved for operation. A big change from the preceding examples is that there is only one eccentric, and this is made (for cost and maintainability reasons) by bolting a lever on the end of the crankpin. To get the required 'lap' and 'lead', a second input is taken from the crosshead. An advantage with this gear was that once set up

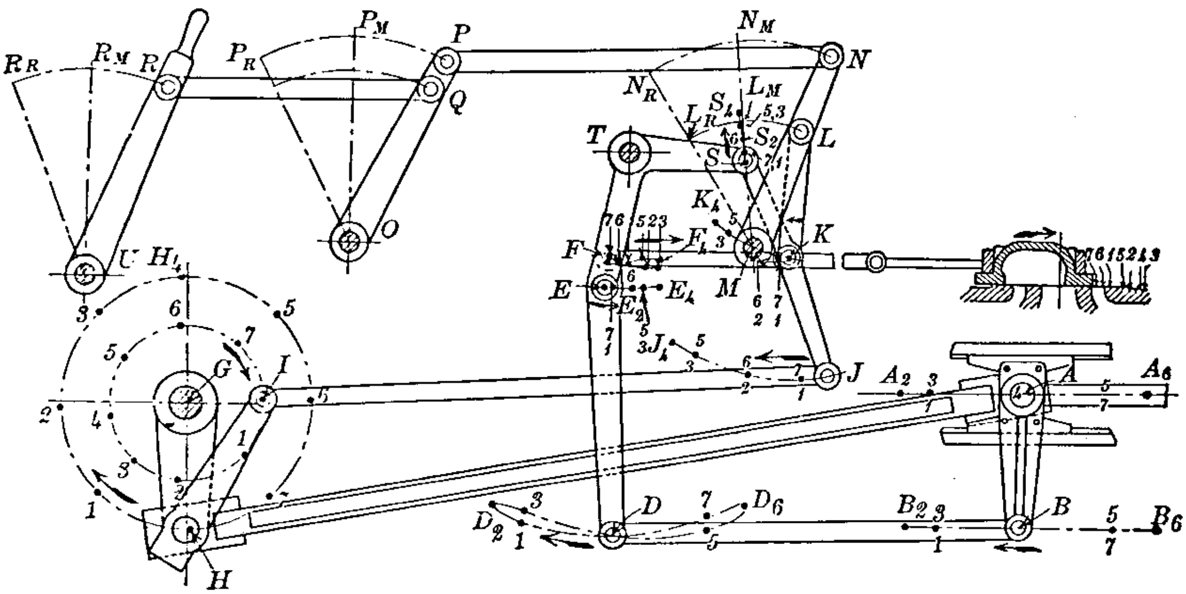

Fig. 8 Baker Valve Gear

correctly, it was easier to maintain than the preceding examples. Finally, Fig. 8 shows the Baker Gear which is what I was trying to get to all along. This gear was also used up to the end of steam locomotives, and depending on who you ask, was either the best gear ever developed for the purpose and an American invention, or just a modification of a good European design (The Walschaert). Whats different about it? The link with it's curved slot is gone. It's therefore cheaper to make and there are no sliding surfaces to wear and become loose in the mechanism, just pinned joints that can be given journal or even ball bearings if desired. If you look closely at the links nearest the valve, you can see an arrangement quite similar to the variable stroke mechanism of Fig. 1. So I've said who needed this mechanism and why, and I've said that the Fig. 1 mechanism was perhaps the best ever developed from a cost, ease of manufacture, and durability point of view. So the last thing I'll say is that in practical application, there is more detail than is seen in these '2-D' pictures (a lot of the links look like wishbones). If you want to see how it was done, go look at an old steam locomotive with the Baker Gear, such as the 125 Texas Type 2-10-4's built from 1942 to 1944, one of which is at the Conneaut Railroad Museum in Conneaut, Ohio.

<u>References</u>

1.) Kinematics of Machinery,Calvin Albert and Fred Rogers, John Wiley & Sons, Inc., N.Y., N.Y., 1931

2.) Valves and Valve Gears, Vol. 1, 2ed Ed., Franklin Furman, John Wiley & Sons, Inc., N.Y., N.Y., 1927