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MAGNETIC CORE STRUCTURE

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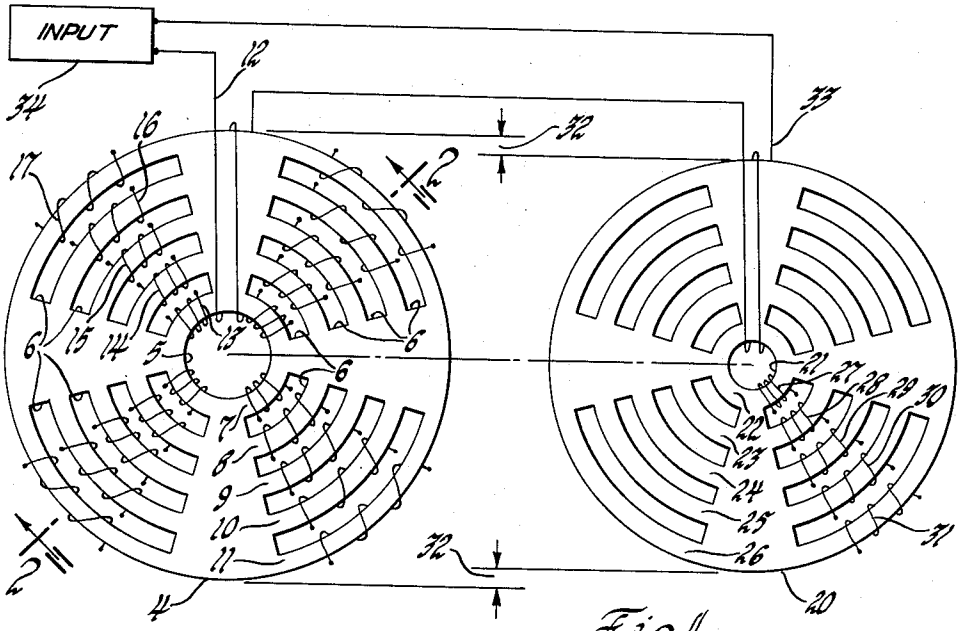


Fig. 1

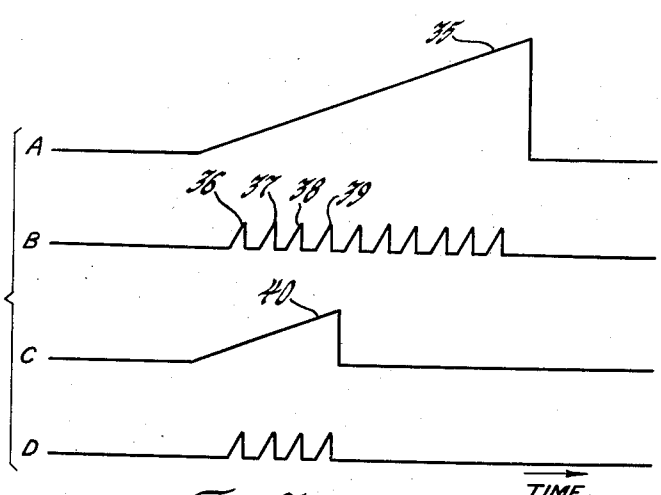


Fig. 3

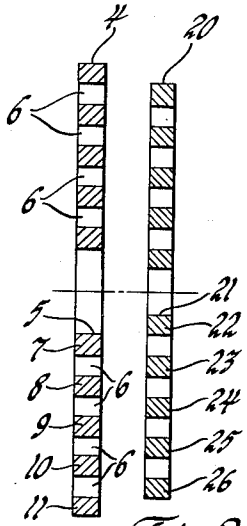


Fig. 2

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MAGNETIC CORE STRUCTURE

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This invention relates to magnetic cores having multiple flux paths and more particularly to magnetic cores adapted for use in analog-to-digital converters.

It is conventional to utilize a closed magnetic core having a plurality of separate flux paths of differing length to convert electrical impulses into unitary digital signals. Apparatus of this type is disclosed in the co-pending applications S.N. 14,372 and S.N. 14,425, both filed March 11, 1960, and assigned to the assignee of the present invention.

In magnetic core converters of this type the output pulses which appear on the separate windings often are not sharp or well defined and are not adequately separated in time from the output of adjacent windings. This is due to the fact that the region of flux change in such a multiple-path core does not have distinct boundaries but is, in fact, a vaguely outlined area which occupies a considerable radial distance in one of the disc-shaped core devices. Thus, the adjacent flux paths not only must be of different lengths, but also they must be separated by a considerable distance. This requirement introduces undesirable characteristics since the coercive M.M.F. of the longer paths is much greater in proportion than in the shorter.

It is the principal object of this invention to provide an improved magnetic core device for use in an analog-to-digital converter. Another object is to provide improved multiple-aperture magnetic core apparatus having a plurality of parallel flux paths of different lengths.

In accordance with this invention at least two magnetic cores are utilized, each having a plurality of flux paths of different lengths as defined by holes or arcuate slots. The two cores differ slightly in size so that, considered together, there are no two flux paths or magnetic circuits which are of the same length. If the two cores are simultaneously driven by an electrical pulse, the shortest path in the smaller core will switch in saturation first, then the shortest path in the larger core, and so forth in alternative succession. Output windings linking each of the separate flux paths will thus provide a series of output pulses which are in time sequence and are related in number to the magnitude of the driving pulse.

The novel features characteristic of this invention are set forth in the appended claims. The invention may best be understood by the following description of illustrative embodiments thereof, read in conjunction with the accompanying drawing, in which:

FIGURE 1 is a diagrammatic representation of converter apparatus incorporating the principal features of this invention;

FIGURE 2 includes a cross-sectional view through the section 2—2 of FIGURE 1; and

FIGURE 3 is a graphic representation of voltage waveforms appearing in the circuit of FIGURE 1.

With reference to FIGURE 1, there is shown a magnetic core in the form of a flat circular disc **4** which is composed of magnetic material having a substantially square hysteresis loop or, in other words, having two stable remanent flux states. The disc **4** includes a center hole **5** and has a plurality of arcuate slots **6** stamped or otherwise formed therein. These slots **6** define a plurality of ring-shaped magnetic circuits or circular flux paths **7–11**. It is noted that the circumferential length of adjacent paths differ by substantial amounts. An input winding **12** links all of the paths **7–11** or the entire closed core by being threaded through the center hole **5**. A plurality of output windings **13–17** are shown linking each of the paths **7–11** separately in the upper left-hand quadrant. The winding **13** is connected in series with the other three output windings in the remaining quadrants of the path **7**. Also, the winding **14** is connected in series with the other three windings on path **8** and the windings **15–17** are in series with windings on the respective flux paths. These connections are omitted in the drawing.

Also there is shown in FIGURE 1 a second magnetic core in the form of a flat circular disc **20** of slightly smaller size. This disc **20**, like the disc **4**, has a center hole **21** and a series of circular flux paths **22–26** defined by a plurality of arcuate slots. One of a plurality of separate output windings **27–31** links each of the flux paths **22–26**. Similar output windings would be provided in each quadrant, but are omitted in the drawing for clarity. The output windings on each path would be connected in series as explained above. The disc **20** is smaller in radius than the disc **4** by an amount **32** which is approximately equal to the width of one of the separate flux paths. An input winding **33**, threading the center hole **21**, links all of the paths **22–26** or the entire core.

The two input windings **12** and **33** are connected in series and both are driven by an input source **34**. This source **34** may include a sampling arrangement to provide ramp input pulses and also a reset pulse generator such as disclosed in the above-mentioned application S.N. 14,372. The source **34** produces current in the input windings **12** and **33** which may have a waveform such as the ramp function **35** shown in FIGURE 3A. If the two cores have been previously saturated in one direction, clockwise for example, then the ramp function **35** will attempt to produce flux around the two cores in the counterclockwise direction. There will be no flux change, however, until the coercive M.M.F. of the shortest path, in this case the path **22**, has been exceeded. At this time the direction of saturation of the path **22** will switch from clockwise to counterclockwise and a pulse **36** will appear on the output winding **27**. Subsequently, the coercive force of the next shortest path, the path **7** in the disc **4**, will be exceeded and an output pulse **37** will appear on the winding **13**. If the input persists as shown, then output pulses **38** and **39** will appear on the output windings **28** and **14** respectively when the flux paths **23** and **8** saturate in that order. If the ramp function **35** is of sufficient amplitude and time duration, all of the flux paths **7–11** and **22–26** will switch their condition of saturation and ten output pulses will appear on the ten separate output windings in sequence as shown in FIGURE 3B. A smaller amplitude input such as the ramp function **40** of FIGURE 3C might be effective to change the condition of saturation in only four of the paths which would be the shortest paths **22**, **7**, **23**, and **8**, in that order. This would produce four output pulses on the separate output windings **27**, **13**, **28**, **14**, as shown in FIGURE 3D.

The advantages of using two separate cores as described above instead of one large core having many more flux paths should be readily apparent. For example, the coercive force for the longer paths in a large core is much greater in proportion than for the shorter paths. This results in non-linearities in the input-output characteristics for the longer paths in a large core. A large number of paths can be provided in a small core by making the paths narrower and by making the slots which define the separate paths smaller. However, this would reduce resolution or would not provide sharply defined output pulses since the paths would be in close

physical proximity and the zones of flux change would overlap several paths. With the present arrangement the paths are of considerable physical size, there is a substantial radial separation of the adjacent paths, and paths adjacent in time sequence are on separate cores. On the other hand, none of the paths are of a length which would produce undesirable output characteristics.

While this invention has been described in terms of an illustrative embodiment, it is of course understood that various modifications may be made by persons skilled in the art. Thus it is contemplated that the appended claims will cover any such modifications as fall within the true scope of the invention.

I claim:

1. In a converter, a pair of magnetic cores, each of said cores having a plurality of apertures therein to define a plurality of parallel magnetic circuits of differing lengths, said cores differing in size to provide a conjugate series of magnetic circuit lengths, input winding means linking all of said magnetic circuits, and output winding means linking each of said magnetic circuits separately.

2. In a converter, a pair of closed magnetic cores having substantially rectangular hysteresis loops, each of said cores having a plurality of apertures therein to define a plurality of parallel magnetic circuits of differing lengths, said cores differing in size to provide a conjugate series of magnetic circuit lengths, and input winding means linking all of said parallel magnetic circuits.

3. In an analog-to-digital converter, a pair of closed magnetic cores having substantially rectangular hysteresis loops, each of said cores having a plurality of apertures therein to define a plurality of parallel magnetic circuits of differing lengths, one of said cores being substantially smaller than the other to provide a conjugate series of magnetic circuit lengths, input winding means linking all of said magnetic circuits, an analog voltage source connected to said input means, and output winding means linking each of said magnetic circuits separately.

4. In a converter, a pair of magnetic cores in the form of circular discs, a plurality of flux paths of differing lengths being formed by a plurality of arcuate slots in each of said cores, one of said cores being smaller than the other to provide a conjugate series of path lengths, an input winding linking all of said flux paths, a source of electrical pulses connected to said input winding, and output windings linking each of said paths separately.

5. In an analog-to-digital converter, a pair of magnetic core devices in the form of circular discs having center holes and being composed of magnetic material having a substantially rectangular hysteresis loop, a plurality of flux paths of differing lengths being formed by a plurality of arcuate slots in each of said discs, one of said discs being smaller than the other to provide a conjugate series of path lengths, an input winding linking all of said paths, an analog voltage source connected to said input winding, and output windings linking each of said paths separately.

6. In a converter, a first circular disc of a magnetic material having a substantially rectangular hysteresis loop, a first series of magnetic flux paths defined by a plurality of arcuate slots in said first disc, a second circular disc of like magnetic material, a second series of magnetic flux paths defined by a plurality of arcuate slots in said second disc, said second disc being smaller in radius than said first disc by an amount substantially equal to the width of one of said flux paths whereby said first and second series are interlaced in lengths, an input winding linking all of said flux paths, and output windings linking each of said paths separately.

7. Magnetic core means comprising a first circular disc of magnetic material, a first series of magnetic flux paths of differing lengths defined by a plurality of radially spaced arcuate slots in said first disc, a second circular disc of magnetic material, a second series of magnetic flux paths of differing lengths defined by a plurality of radially spaced arcuate slots in said second disc, said second disc being smaller in radius than said first disc by an amount substantially equal to the width of one of said flux paths whereby no two of said flux paths are of the same length, an input winding linking all of said flux paths, and a plurality of output windings, one of said output windings linking each of said flux paths individually.

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