April 4, 1950 J. H. REISNER 2,503,173

PERMANENT MAGNETIC ELECTRON LENS SYSTEM

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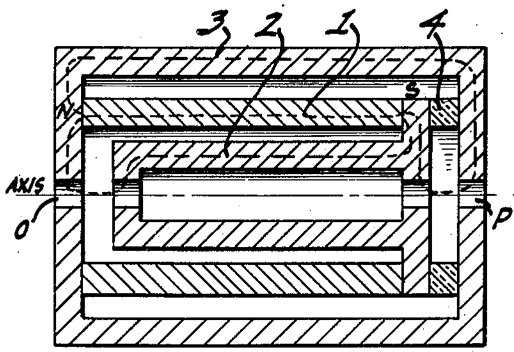

Fig.1.

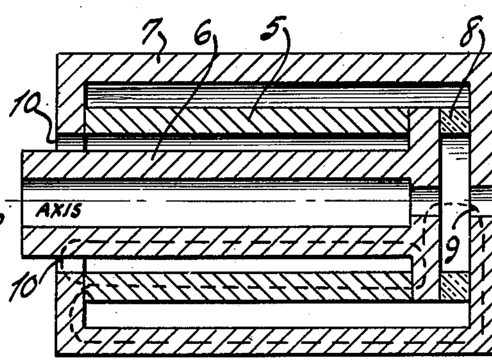

Fig.2.

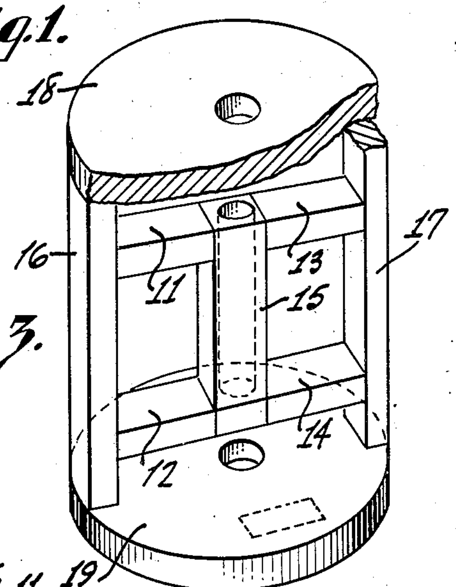

Fig.3.

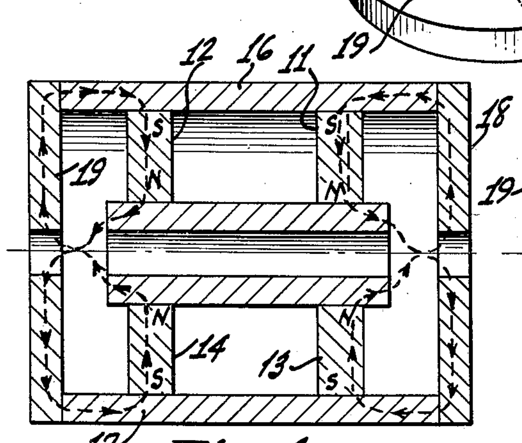

Fig.4.

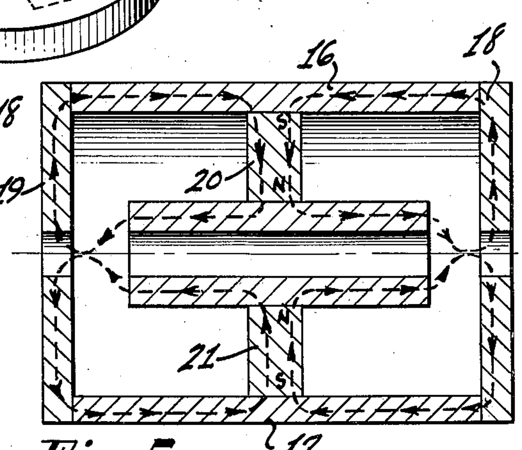

Fig.5.

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PERMANENT MAGNETIC ELECTRON LENS SYSTEM

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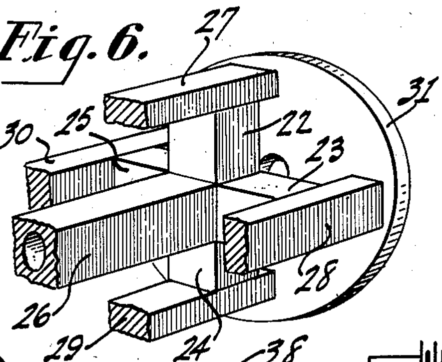
Fig. 6.



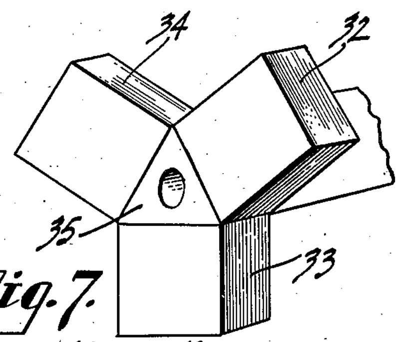


Fig. 7.

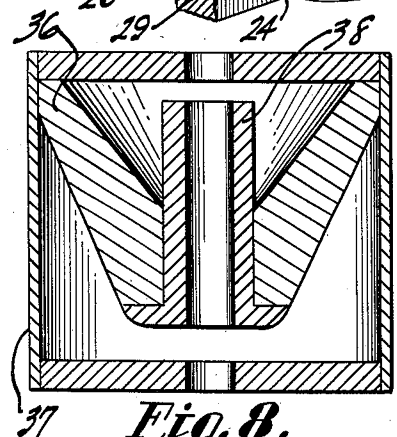


Fig. 8.

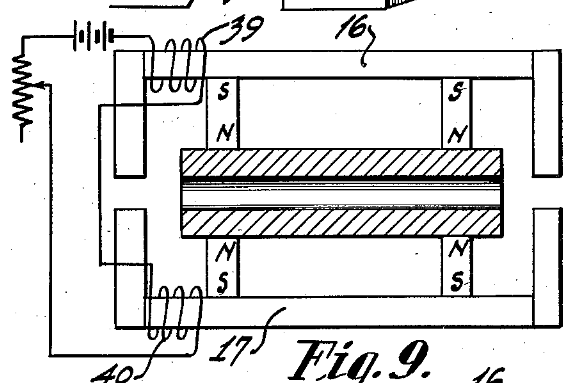
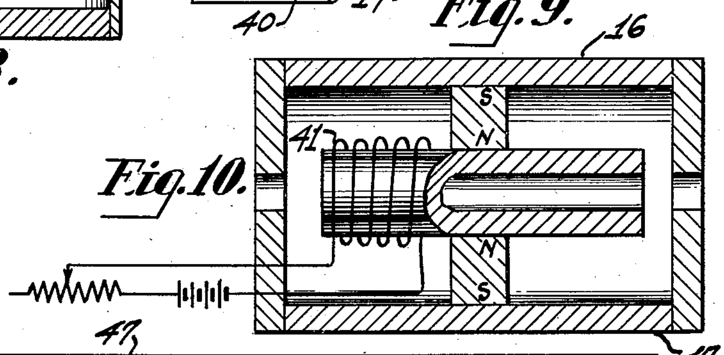


Fig. 9.

Fig. 10.



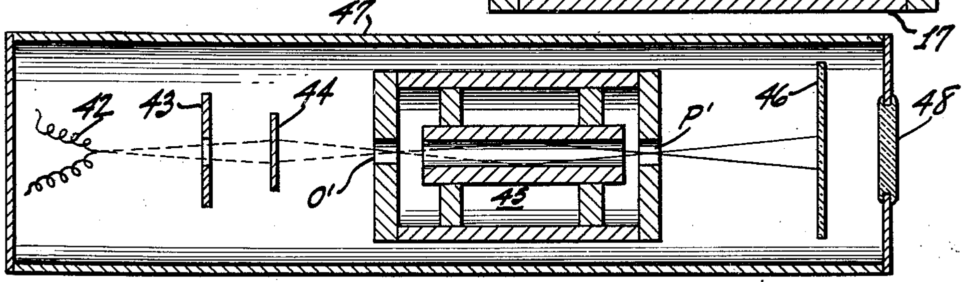


Fig. 11.

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2,503,173

PERMANENT MAGNETIC ELECTRON LENS SYSTEM

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Application October 18, 1946, Serial No. 704,089

12 Claims. (Cl. 250—49.5)

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This invention relates to improvements in apparatus for focusing a stream of electrons and, although not limited to use in apparatus designed for any one purpose, may be advantageously used as a component in an electron microscope.

A means for focusing a stream of electrons is known as an electron lens. Its function is analogous to the function of a lens used for focusing a beam of light. Electron lenses have generally been of two distinct types, electrostatic and magnetic, and the latter class may, in turn, be divided into two divisions, namely, the electromagnetic and the permanent magnetic. The present invention covers improvements in lenses of the magnetic type, which may be either permanent or electromagnetic, although in this particular instance the former is preferred.

One object of the present invention is to provide an improved system of permanent magnetic electron lenses having greatly increased magnification power with good resolution.

Another object is to provide a permanent magnetic electron lens system utilizing the external magnetic flux more efficiently.

Another object is to provide a permanent magnetic electron lens system utilizing a magnetically permeable shield which at the same time serves as part of the magnetic circuit of the lens system.

Another object is to provide an improved permanent magnetic lens system having electromagnetic focusing means.

Another object is to provide an improved electron lens system in which either electromagnetic or permanent magnetic lenses may be used interchangeably.

Still another object is to provide an electron optical lens system to which easy access may be had for changing the magnets or inserting specimens.

These and other objects will be more apparent and the invention will be better understood by reference to the following description taken in connection with the drawings in which:

Fig. 1 is a cross section view of one type of permanent magnetic lens in which the direction of magnetization of the magnets is parallel to the axis of the electron beam.

Fig. 2 is a cross section view of a lens similar to that of Fig. 1 but having only a single flux gap positioned so as to act upon the electron beam.

Fig. 3 is a perspective partial view of another type of permanent magnet electron lens con-

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structed according to the present invention but having the direction of magnetization of the magnets perpendicular to the axis of the lens.

Fig. 4 is a transverse section view of the lens system of Fig. 3 with the principal flux paths indicated.

Fig. 5 is a cross section view of another permanent magnet lens system falling within the scope of the present invention and also having the principal flux paths indicated.

Fig. 6 is a perspective partial view of another type of permanent magnet lens system having the direction of magnetization of its magnets perpendicular to the lens axis.

Fig. 7 is a perspective partial view of still another type in which direction of magnetization is perpendicular to the lens axis.

Fig. 8 is a cross section view of another modification in which a conically shaped magnet is used having its direction of magnetization substantially along an element of the cone.

Fig. 9 shows how the lens system of Fig. 3 may have an electromagnetic focusing control applied to it.

Fig. 10 shows how the same may be applied to the system of Fig. 5.

Fig. 11 is a diagrammatic view of a typical electron microscope showing the position of the lens system in relation to the other parts.

Heretofore, electron lenses have been principally of two types, electromagnetic and electrostatic. With the former, both good resolution and very high magnification are obtainable but electron microscopes using this type of lens are, at best, bulky and relatively expensive. Electron microscopes using electrostatic lenses may be made somewhat more compact but this type of instrument has other disadvantages such as high voltage required between the lenses.

Permanent magnet lens systems because of their relative simplicity of construction and operation have been tried. An example of this type of lens is shown in the patent to Ramberg, No. 2,369,796, and assigned to the present assignee. This type of lens has many advantages over previous magnetic lens types but the highest magnification thus far obtained with it has been below 1000 diameters.

The present invention provides a distinct improvement in design and a somewhat different principle compared to the lens system shown in the Ramberg patent. With the improved type of lens, magnifications of the order of 10,000 diameters with excellent resolution may easily be obtained. These lens systems are so compact that electron microscopes using them may be made quite small and light in weight and their cost is but a fraction of the best previously designed instrument using electromagnetic lenses.

In the electron lens system of the present invention paths of magnetically permeable material have been provided to lead the external flux which always surrounds a magnet to flux gaps which thereby become more strongly energized and exert a greater bending influence on the streaming electrons passing by.

Ordinarily a cylindrical or other shaped permanent magnet lens has a strong external field which reacts upon electrons before they enter the lens itself and prevents the formation of sharp images. Attempts have been made to eliminate the effect of this field on the electron path by shielding the lens with magnetically permeable material. Such a shield also prevents stray external magnetic fields generated by other forces from influencing the operation of the lens which shielding is absolutely necessary for successful operation. This is effective as a preventive measure but the manner in which these shields have been used heertofore did not allow the use of the external flux as part of the energizing force in the lens. In the present invention, however, the shield becomes a part of the flux path with the result that the flux gap has its field greatly intensified.

One modification of a lens system constructed according to the present invention is shown in Fig. 1. This is a cross section view of a typical system having component magnets energized in a direction parallel to the path of travel of the electron beam being acted upon by the lens system. In the figure there is shown a cylindrical magnet 1 having its bases as poles. To one of the bases is attached an inner concentric cylinder 2 of magnetically permeable material having low retentivity which may be soft iron or cold rolled steel. To the opposite base, which is also the opposite pole of the cylindrical magnet is attached an outer concentric shield 3 of similar magnetically permeable material. A spacing ring 4 of non-magnetic material such as brass separates the end pieces of the inner and outer shields.

The magnetic cylinder 1 may be thought of as having an inner and an outer flux circuit in parallel. Part of the path of these circuits is through the cylinder itself and when the cylinder is not associated with any other magnetic substance the return path is through the air. Introducing a magnetically permeable substance into the air path concentrates the flux so that substantially all of it travels through the permeable material instead of through the air. This characteristic of magnets and magnetic fields is well known.

In order to make a double magnetic lens which can be used to focus a beam of electrons it is necessary to establish two flux gaps which will provide a strong field within a small area. In the present case these gaps are formed by attaching pole pieces to the magnet and shaping these pole pieces such that one of them acts not only as an external shield but as a path for leading the outer flux to one of the flux gaps. The inner cylindrical pole piece leads the inner flux to the other flux gap. In this way almost all of the field strength of the magnet is utilized and much higher orders of magnification are possible.

The two gap system provides two magnetic lenses, one of which may constitute an objective lens and the other of which becomes a projector lens as indicated by the letters O and P, respectively, on Fig. 1. With this combination, high magnifications are possible.

For some applications a single gap lens is necessary. For this effect, in which only one of the flux gaps is positioned so that it will affect the focusing of the electrons, it is necessary to move the unused gap away from the electron path. An illustration of this type of lens is shown in the cross section drawing of Fig. 2. This lens has a cylindrical magnet 5, an inner concentric pole piece 6, an outer concentric shield and pole piece 7 and non-magnetic spacer 8. The flux gap at 9 is the only one which influences the focusing of the electrons since the other gap 10 is too far removed to have any effect.

The magnet does not need to be cylindrical in shape. Any hollow tubular form may be used such as square, polygonal, or oval. The form need not even be hollow tubular. The magnet system may consist of one or more bar magnets and the shield and inner conducting member may assume correspondingly limited forms, such as bars.

In the modification of the invention just described the alternate forms of the component magnets have all had their direction of magnetization substantially parallel to the axis of the path of the electron beam or the optical axis of the lens. It is not necessary, however, that the magnets be arranged in this way. They may be placed such that their direction of magnetization is perpendicular to the optical axis of the lens. One illustration of this type is shown in Fig. 3. This figure shows a lens system in which two pairs of bar magnets 11—12 and 13—14 are arranged on opposite sides of a magnetically permeable core 15. All of the magnets have their poles in parallel. Connecting the outer poles of each pair of magnets are magnetically permeable yokes 16 and 17. Spool ends 18 and 19 of magnetically permeable material complete the assembly.

The principal flux paths through this system are shown in Fig. 4. Here it is shown that the outer shield, made up of the yokes 16 and 17 serves as part of the path of the magnetic circuit conducting the flux to the flux gaps where most of it can be utilized.

Fig. 5 shows a longitudinal section view of another modification of the system in which only two bar magnets 20 and 21 are used. The principal flux paths are indicated.

Other examples of combinations of bar magnets which fall within the scope of the invention are shown in the drawings. Fig. 6 is a partial view of one end of a lens system having eight bar magnets. Only four of the magnets appear in the drawing, the other end of the system being an exact duplicate. In the drawing the magnets 22, 23, 24, and 25 are each joined to an inner magnetically permeable core 26 and have their opposite poles connected to magnetically permeable yokes 27, 28, 29, and 30, respectively. The yokes are joined to magnetically permeable end pieces, one of which 31 is illustrated.

Fig. 7 shows how 3 bar magnets 32, 33, and 34 may be grouped symmetrically around a core 31.

The invention is not limited to use of magnets energized either parallel or perpendicularly to the axis of the lens. The magnets may be energized at some other angle such as illustrated in Fig. 8. This figure shows a conically shaped magnet 36 surrounded by a soft iron shield 37 and having soft iron pole pieces 38. In this case the shield also serves as part of the path through which the flux is led to complete the magnetic circuit across the gap.

In the construction of all of these lenses the magnets may be made of any strongly magnetizable metal. It is preferred to use one of the Alnico alloys containing iron, aluminum, nickel, and cobalt but other magnetized material may be used if strength and stability are not primary requirements.

When bar magnets are used they need not be of rectangular cross section since other shapes such as circular or wedge shape will serve equally well.

The modification in which bar magnets are used is perhaps most preferable from a practical standpoint. In this type it is possible to vary the maximum strength over a wide range, by using different numbers of energizing units. Another advantage is that focusing may be changed by changing the position of an auxiliary magnet or a shorting bar. Pole piece gaps and column spaces are accessible for external cooling or temperature control which latter factor is desirable to obtain constancy of gain or resolution. Image rotation can also be reduced to a negligible amount.

The system which has been described is not limited to the one or two gap types which have been illustrated. Any number of units may be assembled together to energize any desired number of gaps.

The focusing of an electron beam using a permanent magnet lens system may be varied just as effectively as in a system using electromagnetic lenses. This may be done in either one of two ways. One way is to vary the accelerating potential of the electrons in order to change their velocity. Another way is to place auxiliary coils in the magnet system and vary the current through them. Figure 9 illustrates how this focusing system may be applied to the lens system of Fig. 3. Two coils **39** and **40** are wound on part of the outer yokes **16** and **17**, respectively, and are energized by a variable source of direct current. Figure 10 shows how a single coil **41** may be wound on the inner core of the system illustrated in Fig. 5.

Any of the lens systems described in the preceding paragraphs may be used in any device in which it is desired to focus a moving stream of electrons. They have particular application in electron microscopes and diffraction cameras. An example of a typical use is shown diagrammatically in Fig. 11. This figure shows the principal elements of an electron microscope including a source of emitted electrons **42** which may be a specially constructed cathode, an aperture **43**, a specimen or object **44** to be examined, a lens system **45**, a fluorescent screen **46** and an enclosing evacuated chamber **47** having a viewing window **48**. The cathode emits a stream of electrons which strike the specimen and at any point being examined these electrons diffuse in a regular pattern. This diffused stream pattern then enters the magnetic lens system where the electron rays are focused by the objective lens O', then focussed again by the projection lens P' after which they are caused to travel to the screen **46**. On the screen, there is projected a highly magnified image of the part of the specimen under observation. The observer views this image from the opposite side of the screen by looking through the viewing window.

Electromagnets may be substituted for the permanent magnets in all of the modifications which have been described. On soft iron cores of suitable size, coils are wound and each coil is energized so as to give it the same polarity as it would have had had the magnet been a permanent one.

There has thus been described an improved electron lens system having, fundamentally, two gaps, one of which is energized by means of flux conducted to the gap through a shielding structure. Thus the magnetically permeable material which acts as the shield also adds to the strength of the lens because of the manner in which it is used. The magnets may be either of the permanent or electro type and electrical focusing means may be included in the system.

I claim as my invention:

1. An electron lens system comprising magnetic means having associated therewith and connected thereto structure constituted of a plurality of members of magnetically permeable material having low retentivity, at least two relatively narrow flux gaps within said lens system, said different members of said permeable structure being connected to opposite poles of said magnetic means and serving as part of the magnetic circuits through the flux gaps, and at least one of the members of said permeable structure surrounding said magnetic means and serving as a shield for the lens system.

2. An electron lens system comprising relatively strongly magnetized magnetic means having at least two flux gaps associated therewith, and shielding means surrounding said magnetic means, said shielding means being constituted of magnetically permeable material with low retentivity connected to one pole of said magnetic means and shaped such that one of said gaps is energized by magnetic flux conducted from said magnetic means and traversing said shielding means.

3. An electron lens system comprising relatively strongly magnetized magnetic means having associated therewith and connected thereto structure constituted of magnetically permeable material having low retentivity, said structure forming at least two flux gaps energized by said magnetic means, and shielding means surrounding said magnetic means and forming part of said magnetically permeable structure shaped such that at least one of said gaps is energized by magnetic flux conducted from said magnetic means and traversing said shielding means.

4. In an apparatus including means for focusing a beam of electrons, an electron lens system comprising a permanent magnet system having its components spaced around a portion of the path of said beam, and having at least two flux gaps, magnetically permeable shielding means connected to and surrounding said magnetic components, said shielding means forming at least part of the path by means of which at least part of the external flux of said magnet components is led to said flux gaps.

5. In an apparatus for focusing a beam of emitted electrons, an electron lens system comprising a permanent magnet system having magnetic means with its direction of magnetization substantially parallel to the axis of the lens system, and with its component parts arranged axially about said electron beam, said magnet system having an inner and an outer flux path and having two gaps provided by attached pole pieces, one of said gaps being energized by flux traversing said inner path and the other of said gaps being energized by flux traversing said outer

path with at least one of said gaps being positioned so that its field exerts a focusing effect on the electrons in said beam.

6. An electron lens system comprising a hollow tubular permanent magnet having bases as poles and having an inner and an outer flux path, said magnet having two gaps provided by attached pole pieces shaped such that one of said gaps is energized by flux traversing said inner path while the other of said gaps is energized by flux traversing said outer path.

7. An electron lens system comprising a hollow tubular permanent magnet having bases as poles and having an inner and outer flux path, said magnet having two gaps provided by separate magnetically permeable structures attached to opposite poles of said magnet, the first of said structures serving as a path for said inner flux and the second of said structures serving as a path for said outer flux, whereby the first of said gaps is energized by the flux traversing said inner path and the second of said gaps is energized by the flux traversing said outer path.

8. An electron lens system comprising a hollow tubular permanent magnet having bases as poles, an inner concentric shell of magnetically permeable material attached to one of said poles and forming a flux gap adjacent the other of said poles, and an outer concentric shell of magnetically permeable material attached to said second mentioned pole and forming a flux gap adjacent said first mentioned pole.

9. In an apparatus for forming a beam of emitted electrons, an electron lens system comprising a hollow tubular magnet having bases as poles and having an inner and an outer flux path, said magnet having two gaps provided by separate magnetically permeable members attached to opposite poles of said magnets, one of said members serving as the path of said inner flux and the other of said members serving as the path of said outer flux, whereby the first of said gaps is energized by the flux traversing said inner path and the second of said gaps is energized by the flux traversing said outer path and at least one of said gaps being positioned so that its field influences the direction of travel of the electrons in said beam.

10. In apparatus for focusing a beam of emitted electrons, an electron lens system comprising a magnetic system having its component magnets arranged axially around a portion of the path of said beam, separate magnetically permeable means connected to the opposite poles of said component magnets for conducting substantially all of the external flux to flux gaps positioned at predetermined points, said gaps being so placed that at least one of them influences the direction of travel of the electrons in said beam.

11. An electron lens system comprising magnetic means having its direction of magnetization perpendicular to the lens axis, at least two flux gaps within said lens system, separate magnetically permeable members of low retentivity connected to opposite poles of said magnetic means and serving as part of the magnetic circuits through the flux gaps.

12. An electron lens system comprising magnetic means, at least two flux gaps within said lens system, separate members constituted of magnetically permeable material having low retentivity connected to opposite poles of said magnetic means and serving as part of the magnetic circuits through the flux gaps, and electromagnetic means for controlling the focusing of the lenses in said system.

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REFERENCES CITED

The following references are of record in the file of this patent:

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Number	Name	Date
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