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Voishvillo

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(54) **PHASING PLUG FOR A COMPRESSION DRIVER**

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(21) Appl. No.: **13/270,102**

(22) Filed: **Oct. 10, 2011**

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Related U.S. Application Data

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(51) **Int. Cl.**
H04R 1/20 (2006.01)

(52) **U.S. Cl.**
USPC **381/343**; 381/340; 181/177; 181/179; 181/182; 181/184; 181/185; 181/187; 181/188

(58) **Field of Classification Search**
USPC 381/343; 181/177–195
See application file for complete search history.

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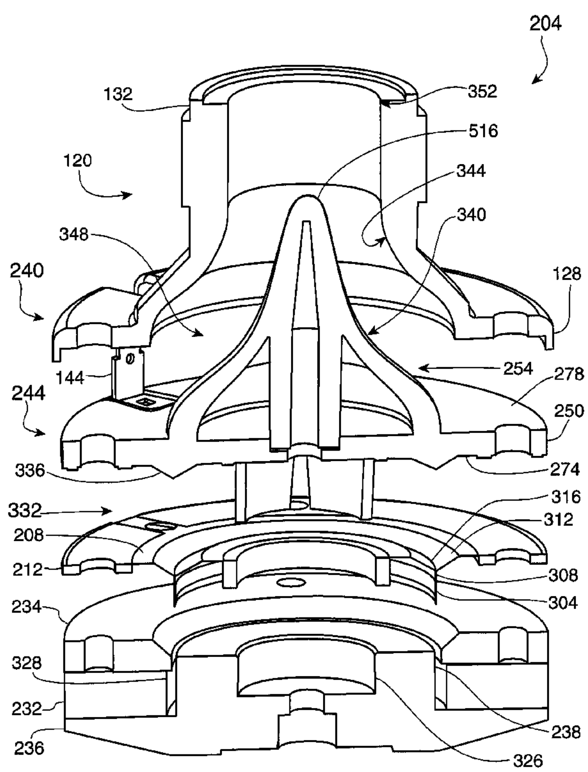
(57) **ABSTRACT**

A phasing plug for a compression driver includes a base portion and a hub portion. The base portion includes a first side, a second side, and a plurality of apertures extending between the first and second sides. The hub portion extends from the base portion along an axis. The hub portion includes an outer surface and a plurality of ribs disposed on the outer surface. A plurality of recesses are defined by the outer surface and respective pairs of adjacent ribs. At least one aperture fluidly communicates with at least one of the recesses.

26 Claims, 14 Drawing Sheets



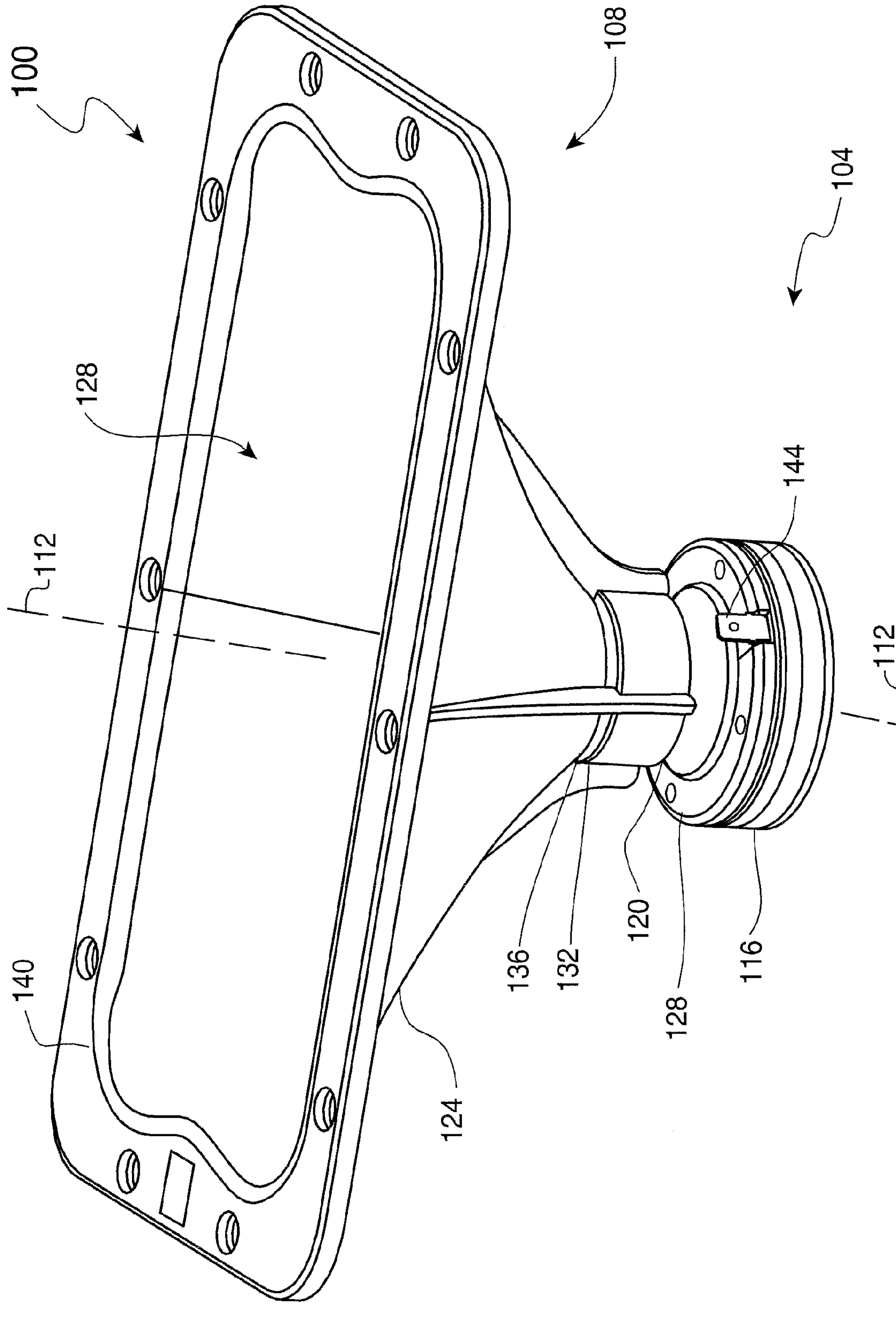
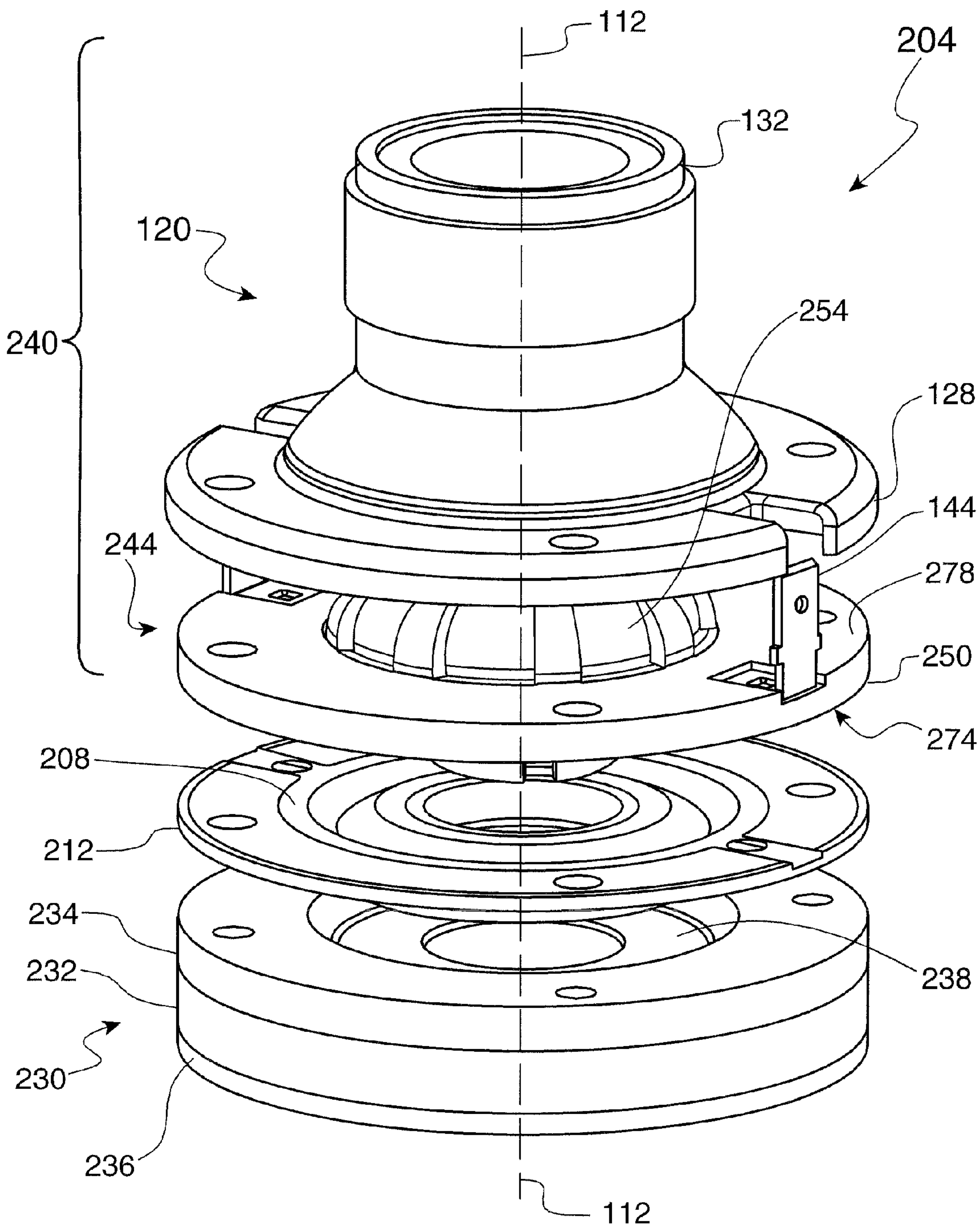


FIG. 1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204
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112

FIG. 2

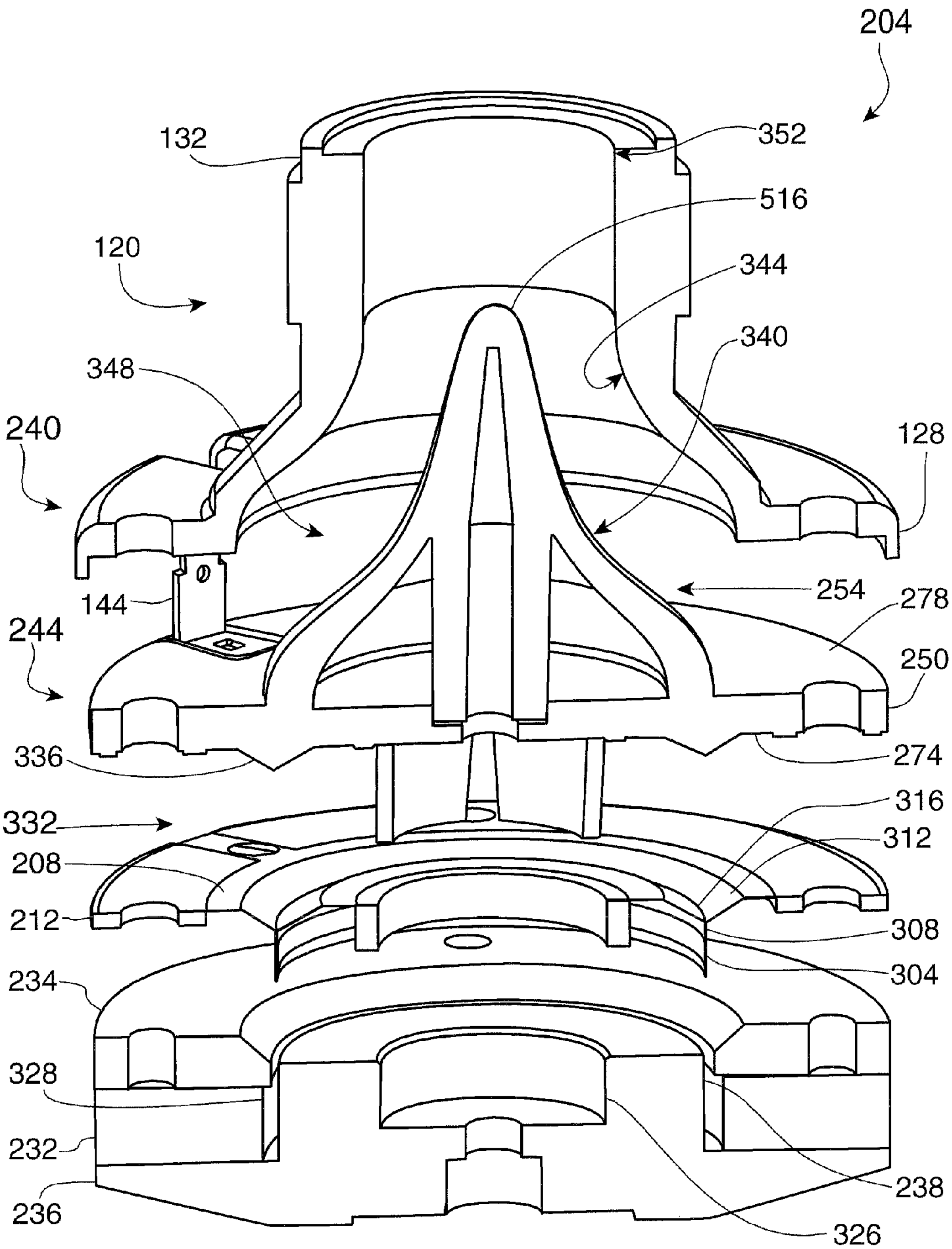
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FIG. 3

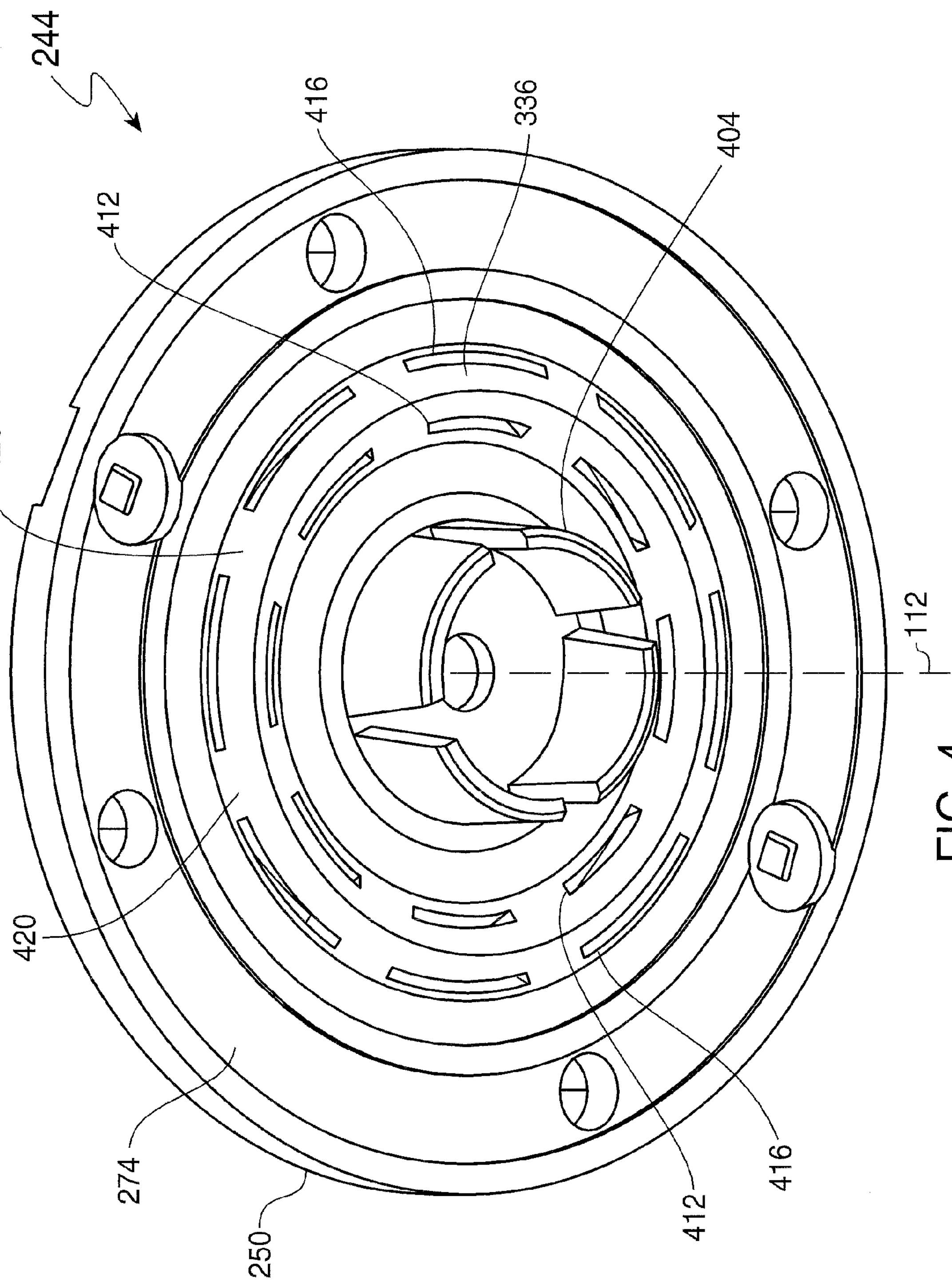
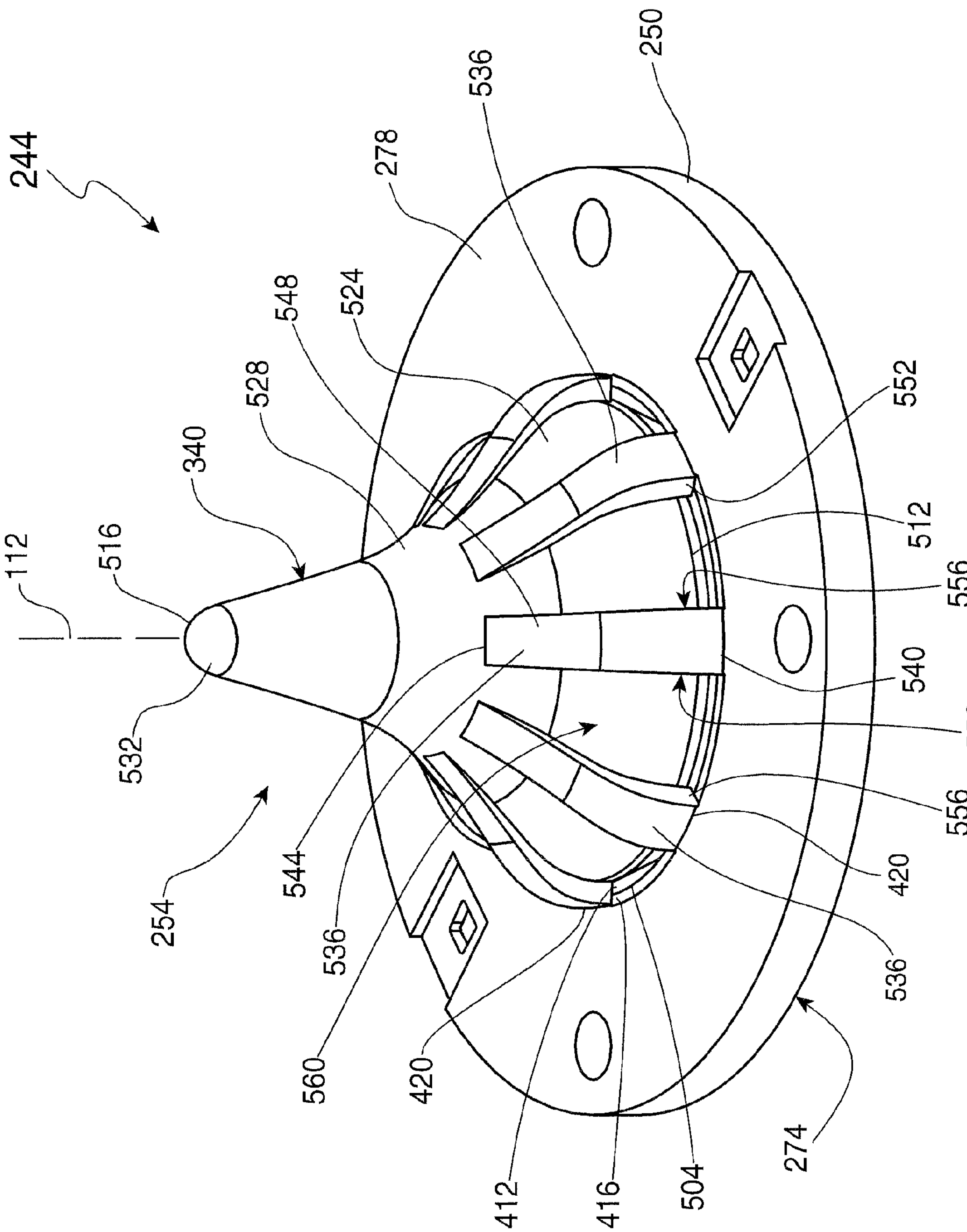


FIG. 4


244
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278
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340
112
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552
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420
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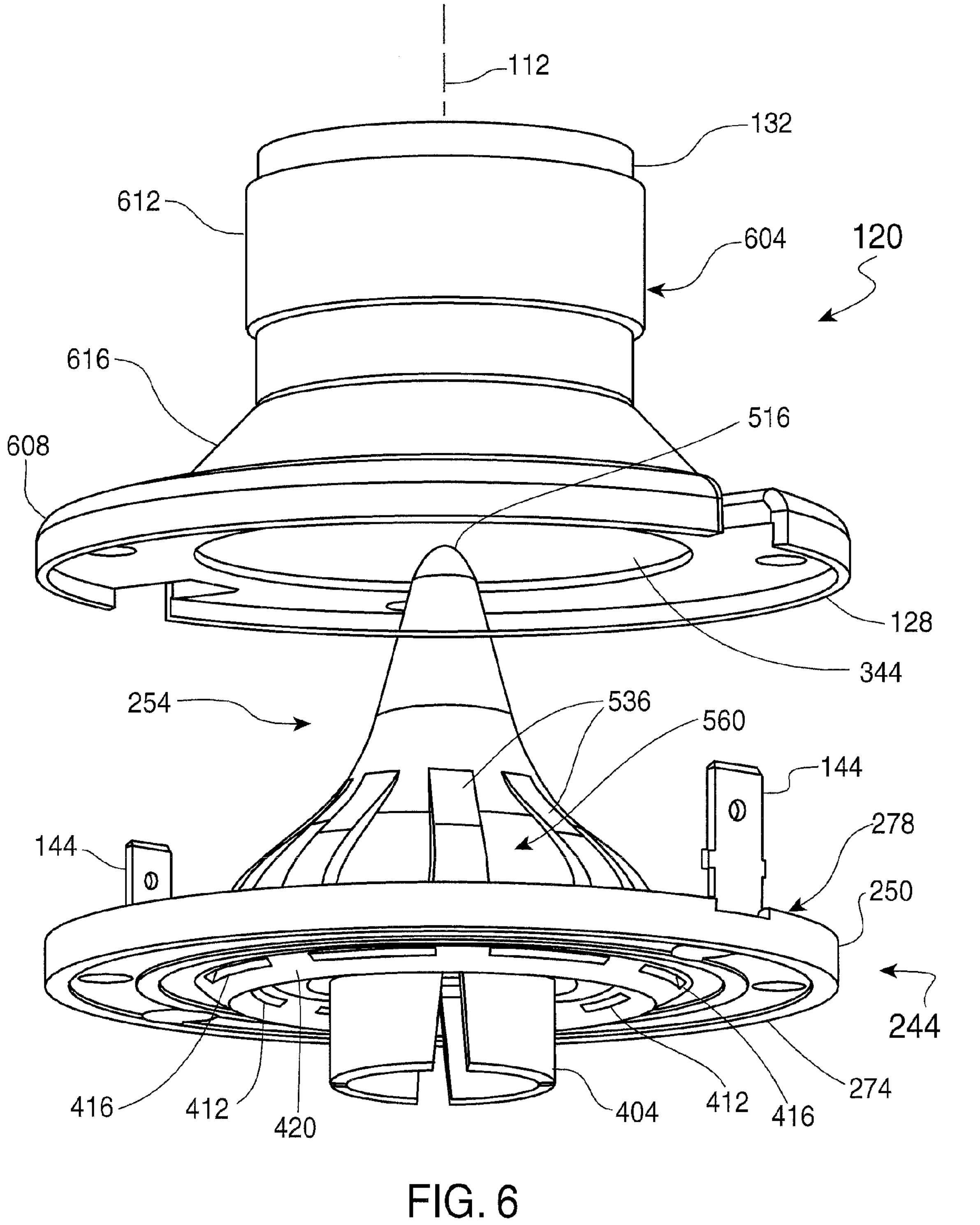
420
412
416
504
274

FIG. 5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612
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120
616
516
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344
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536
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144
144
278
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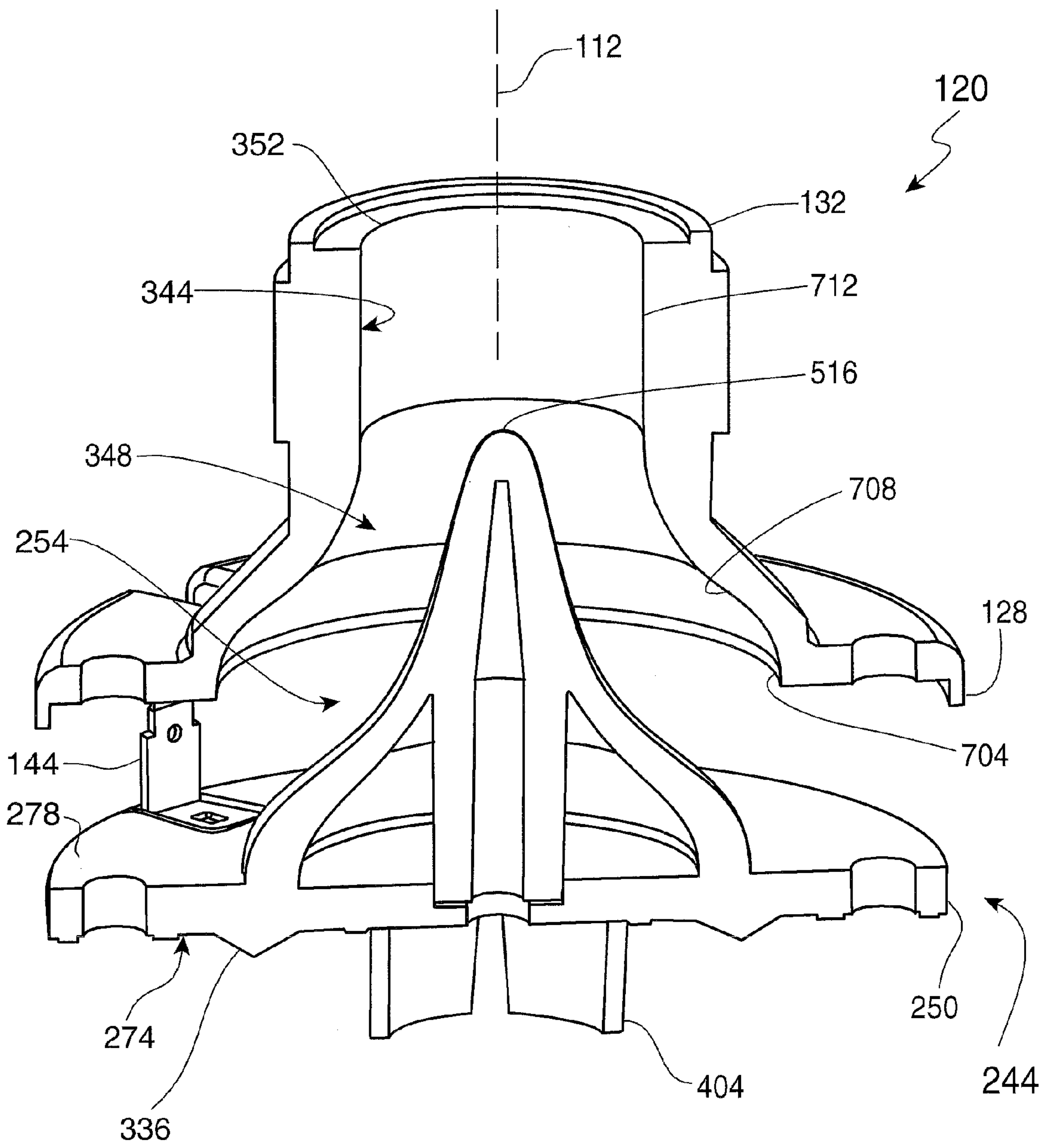
244
416
412
420
404
412
416
274

FIG. 6


112
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352
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404

FIG. 7

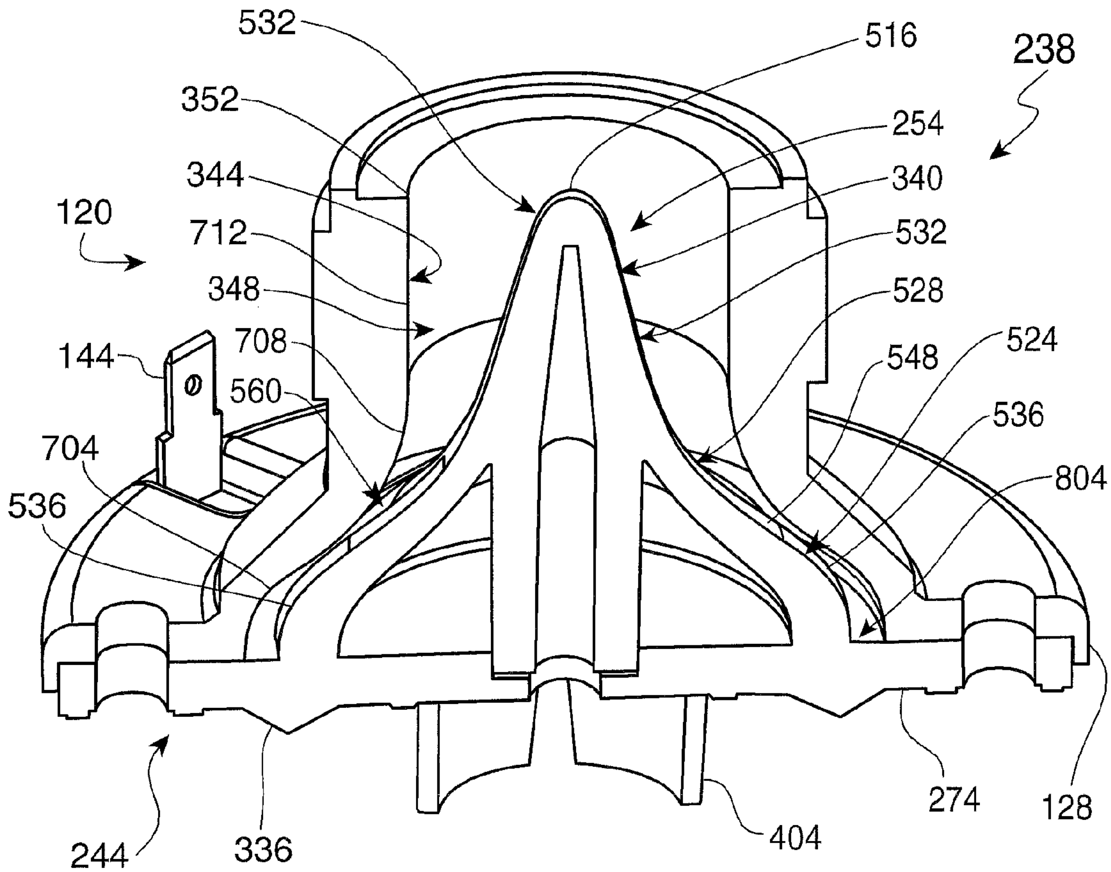
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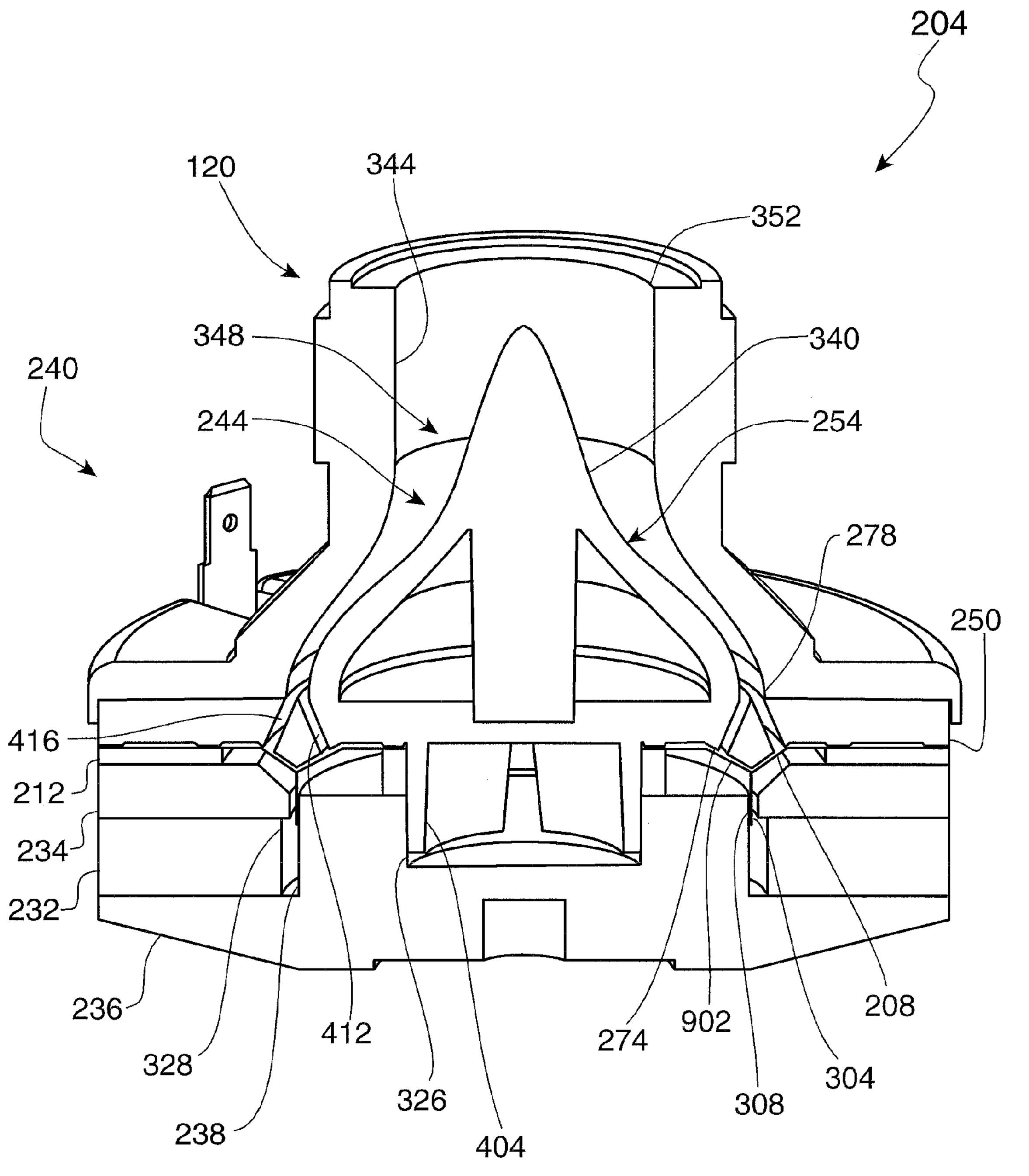
FIG. 8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902
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304
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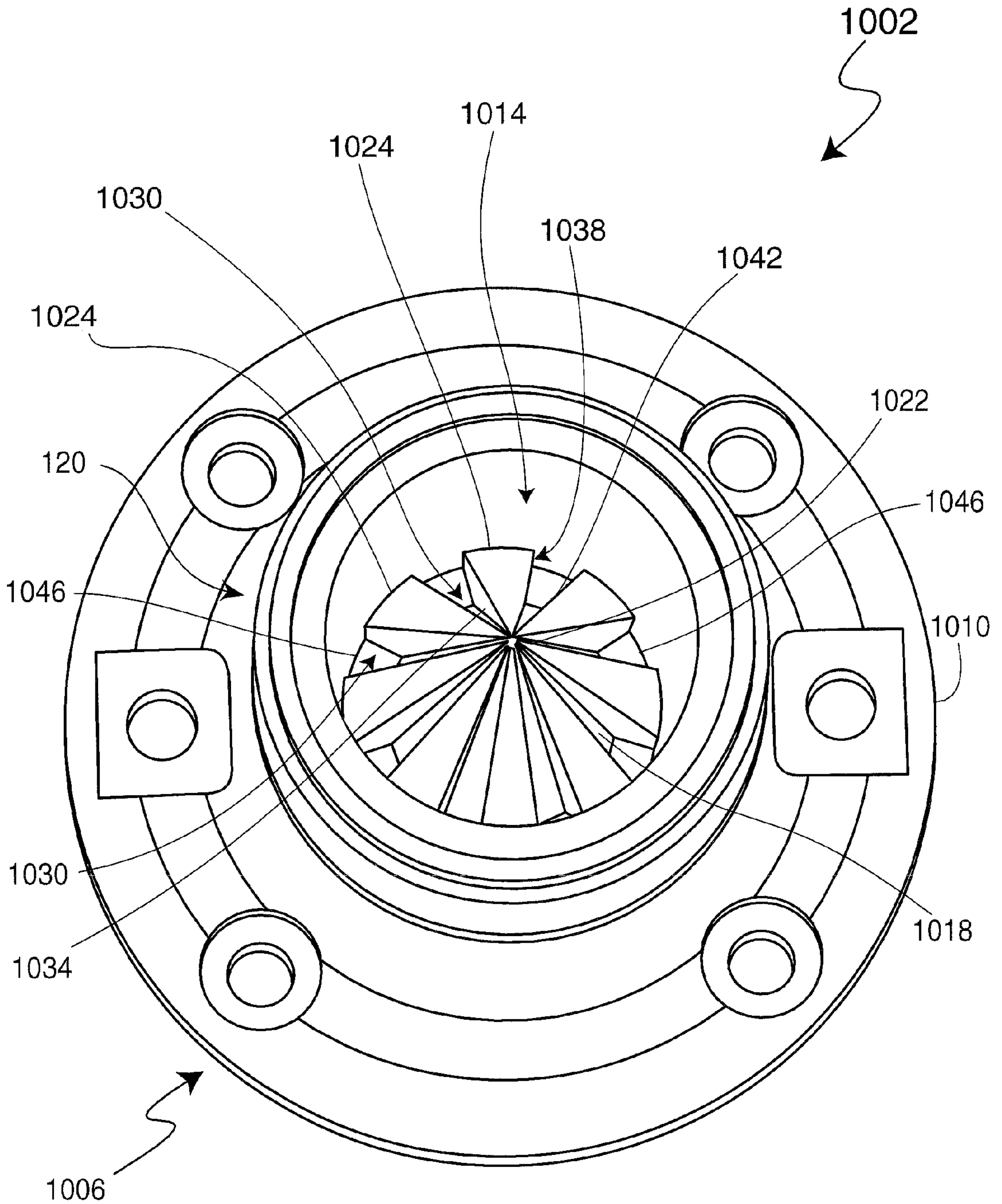
FIG. 9


1002
1014
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1038
1042
1024
1022
120
1046
1046
1010
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1018
1034
1006

FIG. 10

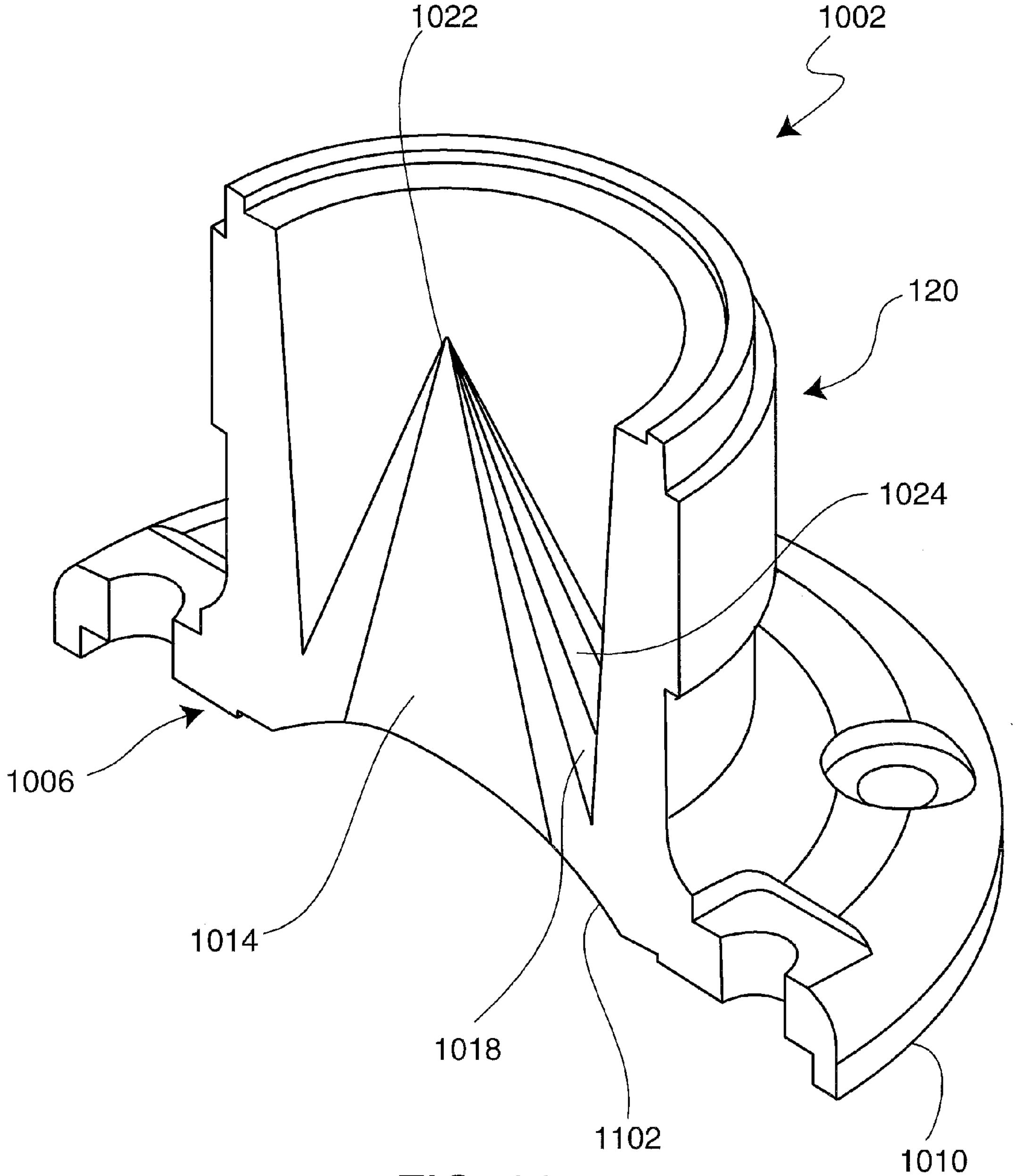

FIG. 11

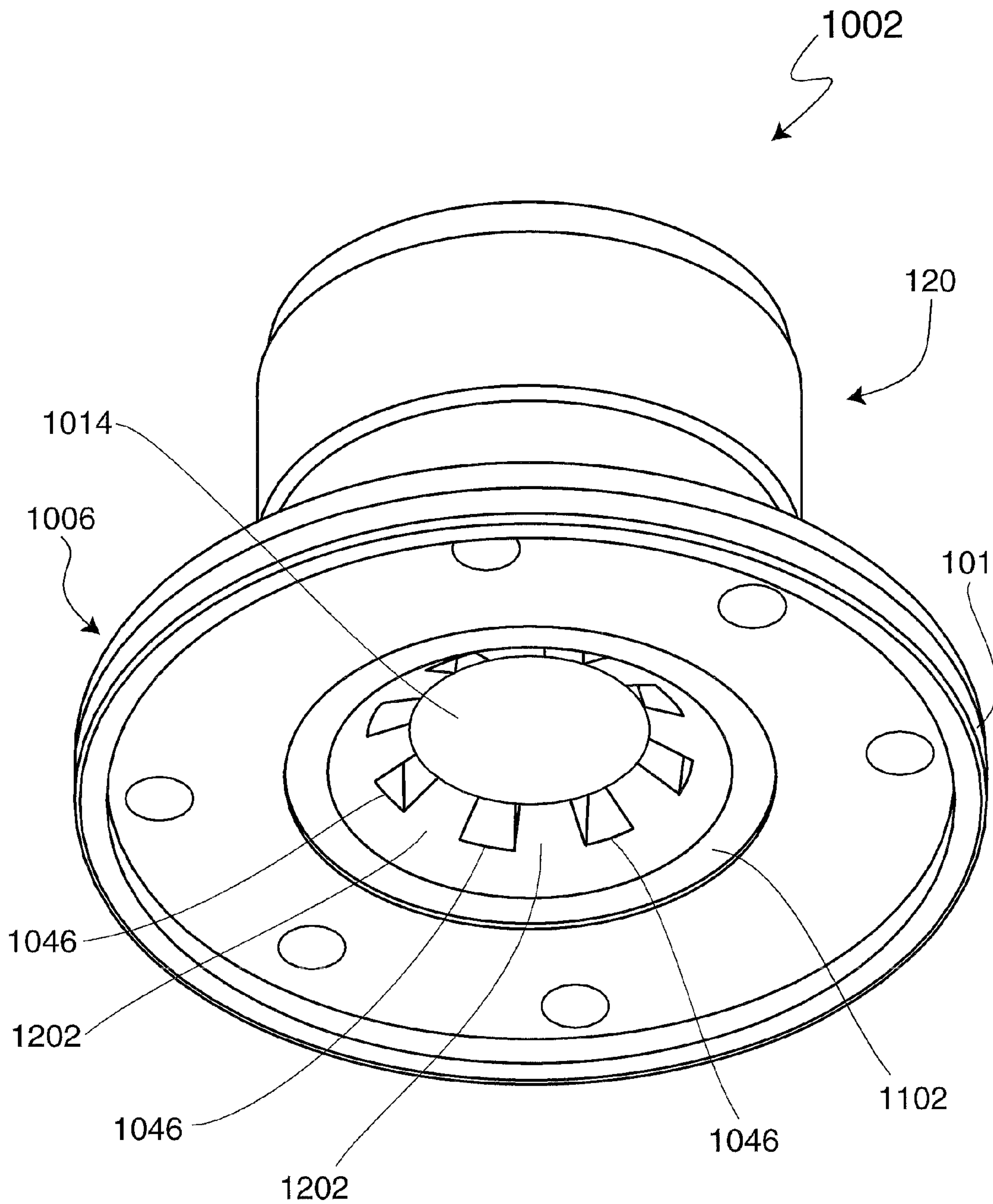

FIG. 12

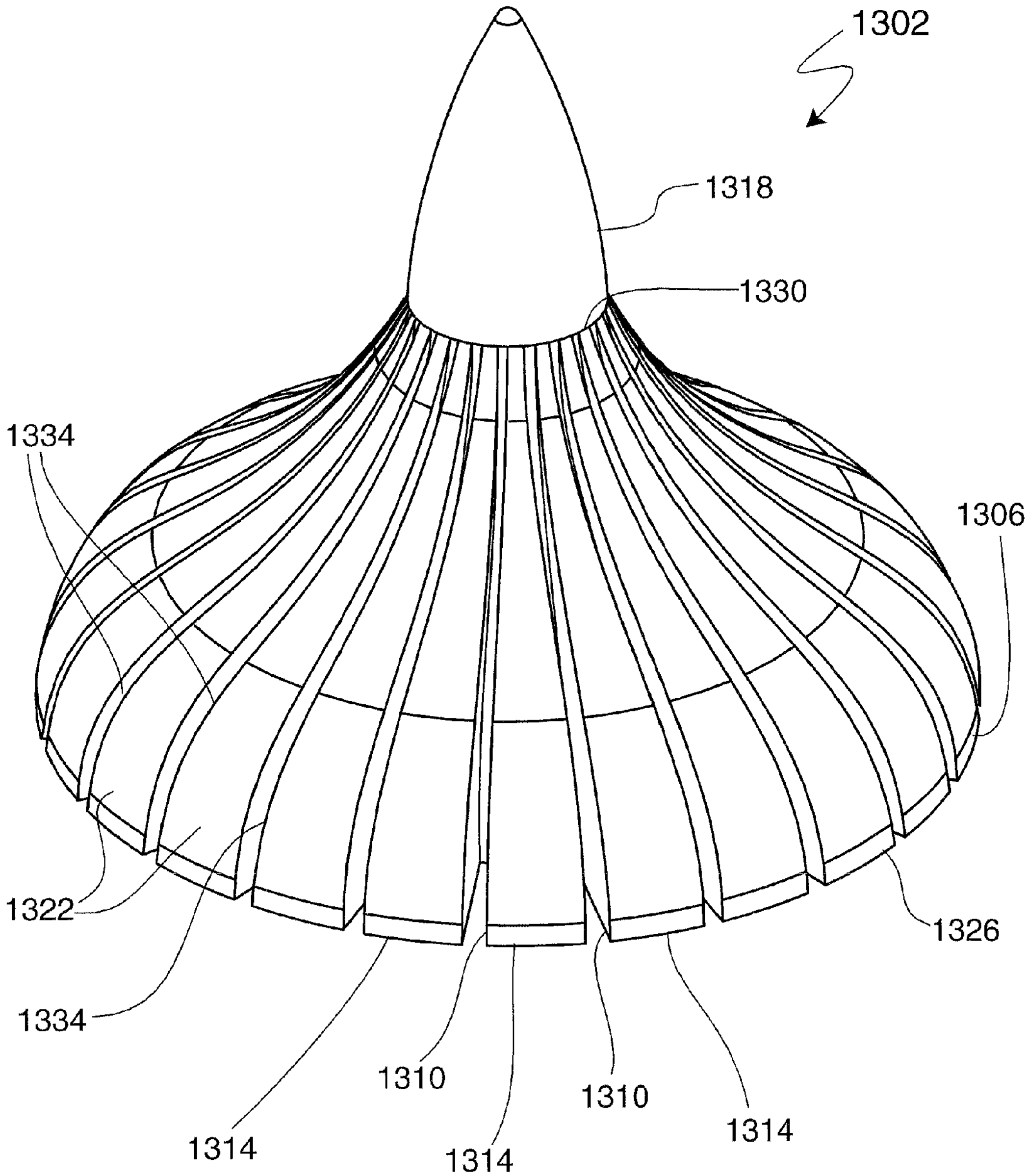
1302
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FIG. 13

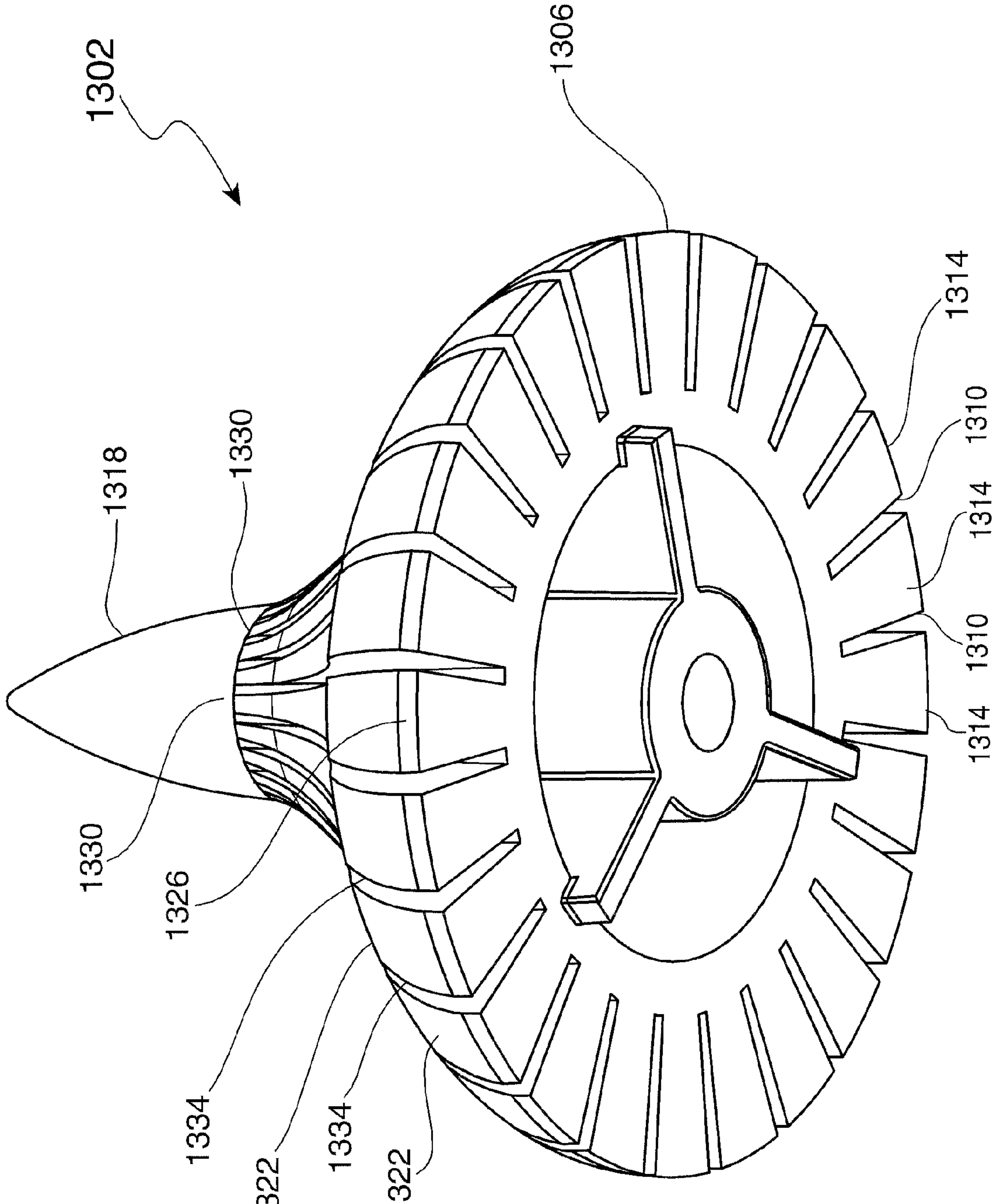
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FIG. 14

PHASING PLUG FOR A COMPRESSION DRIVER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation and claims priority to U.S. application Ser. No. 11/317,654, filed on Dec. 22, 2005, titled PHASING PLUG FOR A COMPRESSION DRIVER, which application is incorporated by reference in this application in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to electro-acoustical drivers and loudspeakers employing electro-acoustical drivers. More particularly, the invention relates to improved configurations for compression drivers.

2. Related Art

An electro-acoustical transducer or driver is utilized as a loudspeaker or as a component in a loudspeaker system to transform electrical signals into acoustical ones. The basic designs and components of various types of drivers are well-known and therefore need not be described in detail. Briefly, a driver receives electrical signals and converts the electrical signals to acoustic signals. The driver typically includes mechanical, electromechanical, and magnetic elements to effect this conversion. For example, the electrical signals may be directed through a circular voice coil that is attached to diaphragm and the voice coil positioned in an air gap with a radially oriented permanent magnetic field provided by a permanent magnet and steel elements of a magnet assembly. Due to the Lorenz force affecting the conductor of current positioned in the permanent magnetic field, the alternating current corresponding to electrical signals conveying audio signals actuates the voice coil to reciprocate back and forth in the air space and, correspondingly, move the diaphragm to which the coil is attached. The voice coil may be attached to a flexible diaphragm that is suspended by one or more supporting elements (e.g., a surround, spider, or the like) such that at least a portion of the diaphragm is permitted to move. Accordingly, the reciprocating voice coil actuates the diaphragm to likewise reciprocate and, consequently, produce acoustic signals that propagate as sound waves through a suitable fluid medium such as air. Pressure differences in the fluid medium associated with these waves are interpreted by a listener as sound. The sound waves may be characterized by their instantaneous spectrum and level.

The driver at its output side may be coupled to an acoustic waveguide, which is a structure that encloses the volume of medium into which sound waves are first received from the driver. The waveguide may be designed to increase the efficiency of the transducer and control the directivity of the propagating sound waves. The waveguide typically includes one open end coupled to the driver, and another open end or mouth downstream from the driver-side end. Sound waves produced by the driver propagate through the waveguide and are dispersed from the mouth to a listening area. The waveguide is often structured as a horn or other flared structure such that the interior defined by the waveguide expands or increases from the driver-side end to the mouth.

Electro-acoustical transducers or drivers may be characterized into two broad categories: direct-radiating types and compression types. A direct-radiating transducer produces sound waves and radiates these sound waves directly into open air (i.e., the environment ambient to the loudspeaker), whereas a compression driver first produces sound waves in a high-pressure enclosed volume, or compression chamber, before radiating the sound waves to the typically much lower-pressure open-air environment. The compression chamber is open to a structure commonly referred as a phasing plug that works as a connector between the compression chamber and the horn. The area of the entrance to the phasing plug is smaller than the area of the diaphragm. This provides increased efficiency compared to a direct-radiating loudspeaker. In a direct-radiating loudspeaker, the output mechanical impedance of the vibrating diaphragm is significantly higher than the radiation impedance that causes "generator" (diaphragm) and "load" (radiation impedance) mismatch. In a compression driver, the loading impedance (entrance to the phasing plug) is significantly higher than the open air radiation impedance. This produces much better matching between "generator" and "load" and increases the efficiency of the transducer. The relative advantages and disadvantages of direct-radiating drivers and compression drivers are well-known to persons skilled in the art. Generally, compression drivers are considered to be superior to direct-radiating drivers for generating high sound-pressure levels. The present disclosure is primarily directed to compression drivers.

As noted, a compression driver utilizes a compression chamber on the output side of the diaphragm to generate relatively higher-pressure sound energy prior to radiating the sound waves from the loudspeaker. Typically, a phasing plug is interposed between the diaphragm and the waveguide or horn portion of the loudspeaker, and is spaced from the diaphragm by a small distance (typically a fraction of a millimeter). Accordingly, the compression chamber is bounded on one side by the diaphragm and on the other side by the phasing plug. The phasing plug is typically perforated in some fashion. That is, the phasing plug includes apertures (i.e., passages or channels) that extend between the compression chamber and the waveguide or horn portion of the loudspeaker to provide acoustic pathways from the compression chamber to the waveguide. The cross-sectional area of the apertures is small in comparison to the effective area of the diaphragm, thereby providing air compression and increased sound pressure in the compression chamber.

The compression driver, characterized by having a phasing plug and a compression chamber, can provide a number of advantages if properly designed. These advantages may include increasing the efficiency with which the mechanical energy associated with the moving diaphragm is converted into acoustic energy. Decreasing the parasitic compliance of air in the compression chamber prevents undesired attenuation of high-frequency acoustic signals. Proper position of apertures in the phasing plug and the lengths of the passages provide delivering sound energy in phase from all parts of the diaphragm, suppressing or canceling high-frequency standing waves in the compression chamber, and reducing or eliminating undesired interfering cancellations in the propagating sound waves.

It is well-recognized by persons skilled in the art that an ongoing need exists for providing improved designs for compression drivers so as to more fully attain their advantages such as high-frequency efficiency, while ameliorating their disadvantages such as detrimental acoustical non-linear effects, irregularity of frequency response, and limited frequency range.

SUMMARY

According to one implementation, a phasing plug for a compression driver is provided. The phasing plug comprises a base portion and a hub portion. The base portion includes a first side, a second side, and a plurality of apertures extending between the first and second sides. The hub portion extends from the base portion along an axis. The hub portion includes an outer surface and a plurality of ribs disposed on the outer surface. A plurality of recesses is defined by the outer surface and respective pairs of adjacent ribs. At least one aperture fluidly communicates with at least one of the recesses.

According to another implementation, a phasing plug for a compression driver is provided. The phasing plug comprises a housing, a base portion, and a hub portion. The housing includes an inner surface defining an interior and an outlet. The base portion includes a first side, an opposing second side generally facing the interior, a plurality of apertures extending between the first and second sides, and a plurality of bridge sections. Each bridge section is interposed between a corresponding pair of adjacent apertures. The hub portion extends from the base portion into the housing along an axis. The hub portion includes an outer surface disposed coaxially about the axis and a plurality of ribs extending from the outer surface. Each rib includes a first rib end disposed at a corresponding bridge section and a second rib end disposed at a distance from the first rib end. A plurality of recesses are respectively defined between pairs of adjacent ribs. Each aperture fluidly communicates with at least one recess. The inner surface and the outer surface cooperatively define a waveguide generally extending from the apertures to the outlet. At least a portion of the waveguide proximate to the apertures is further defined by the recesses.

According to another implementation, a compression driver is provided. The compression driver includes a housing including an inner surface at least partially defining an interior of the housing, a phasing plug disposed in the housing, and a compression chamber defined between the diaphragm and the phasing plug. The phasing plug includes a plurality of apertures providing a plurality of respective fluid passages from the compression chamber to the housing interior, a hub portion disposed in the interior and including an outer surface, a plurality of ribs protruding outwardly from the outer surface, and a plurality of recesses interposed between respective pairs of adjacent ribs. Each rib fluidly communicating with at least one of the apertures.

Other devices, apparatus, systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE FIGURES

The invention can be better understood by referring to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. In the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. **1** is a perspective view of an example of a horn loudspeaker in which a compression driver as described below may be implemented.

FIG. **2** is an exploded perspective view of a compression driver that may be provided with the loudspeaker of FIG. **1**.

FIG. **3** is an exploded cross-sectional view of the compression driver illustrated in FIG. **2**.

FIG. **4** is a perspective view of an example of a phasing plug that may be utilized in the compression driver illustrated in FIGS. **2** and **3**, specifically from the perspective of the input side of the phasing plug.

FIG. **5** is a perspective view of the phasing plug illustrated in FIG. **4**, specifically from the perspective of the output side of the phasing plug.

FIG. **6** is a perspective, exploded view of the phasing plug and an example of an adapter or housing prior to assembly of the phasing plug with the housing.

FIG. **7** is a perspective, exploded view in cross-section of the phasing plug and adapter illustrated in FIG. **6**.

FIG. **8** is a perspective cross-sectional view of the phasing plug and adapter illustrated in FIGS. **6** and **7** after assembly.

FIG. **9** is a perspective cross-sectional view of the compression driver in assembled form.

FIG. **10** is a perspective view of a phasing plug assembly according to another implementation.

FIG. **11** is a perspective cut-away view of the phasing plug assembly illustrated in FIG. **10**.

FIG. **12** is another perspective view of the phasing plug assembly illustrated in FIG. **10**.

FIG. **13** is a perspective view of a phasing plug according to another implementation.

FIG. **14** is another perspective view of the phasing plug illustrated in FIG. **13**.

DETAILED DESCRIPTION

In general, the term "communicate" (for example, a first component "communicates with" or "is in communication with" a second component) is used in the present disclosure to indicate a structural, functional, mechanical, electrical, optical, magnetic, ionic or fluidic relationship between two or more components (or elements, features, or the like). As such, the fact that one component is said to communicate with a second component is not intended to exclude the possibility that additional components may be present between, and/or operatively associated or engaged with, the first and second components.

Examples of implementations of the present subject matter will now be described with reference to FIGS. **1**-**14**.

FIG. **1** illustrates a perspective view of an example of a horn loudspeaker **100** in which a compression driver as described below may be implemented. The loudspeaker **100** includes an electro-acoustical transducer section **104**. In some implementations, the loudspeaker **100** may also include a waveguide or horn **108**. The transducer section **104** and horn **108** are generally disposed about a central axis **112**. The transducer section **104** may include a rear section **116** and a housing or adapter **120**. The rear section **116** may be coupled to the housing **120** by any suitable means. The rear section **116** and housing **120** may enclose components for realizing a driver of the compression type, an example of which is described below. The horn **108** may include a horn structure **124** such as one or more walls that enclose an interior **128** of the horn **108**. As illustrated, the horn structure **124** may be flared or tapered outwardly from the central axis **112** to provide an expanding cross-sectional area through which sound waves propagate. The housing **120** generally includes a first or input end **128** and a second or output end **132**. Likewise, the horn **108** generally includes a first or input end **136** and a second or output end commonly referred to as a mouth **140**. The output end **132** of the housing **120** may be coupled to the input end **136** of the horn **108** by any suitable means. Generally, the loudspeaker **100** receives an input of electrical signals at an appropriate connection such as contacts **144** provided by the transducer section **104** (such as may be located at the rear section **116**) and converts the electrical signals into acoustic signals according to mechanisms briefly summarized above and readily appreciated by persons skilled in the art. The acoustic signals propagate through the interior of the housing **120** and horn **108** and exit the loudspeaker **100** at the mouth **140** of the horn **108**.

As a general matter, the loudspeaker **100** may be operated in any suitable listening environment such as, for example, the room of a home, a theater, or a large indoor or outdoor arena. Moreover, the loudspeaker **100** may be sized to process any desired range of the audio frequency band, such as the high-frequency range (generally 2 kHz-20 kHz) typically produced by tweeters, the midrange (generally 200 Hz-5 kHz) typically produced by midrange drivers, and the low-frequency range (generally 20 Hz-200 Hz) typically produced by woofers. As appreciated by persons skilled in the art, loudspeakers **100** of the horn driver-type are particularly advantageous when utilized to process relatively high frequencies (i.e., midrange to high range), and compression drivers are typically more efficient at higher frequencies than non-compression driver configurations such as the direct-radiating type.

FIG. **2** is an exploded perspective view of an example of a compression driver **204** and associated components and features that may be provided as parts of the transducer section **104** (FIG. **1**) of the horn loudspeaker **100**. The compression driver **204** may include a flexible diaphragm **208**, one or more suspension members **212** for supporting the diaphragm **208** while enabling the diaphragm **208** to oscillate, and a magnet assembly **230** that may comprise an annular permanent magnet **232**, an annular top plate **234**, and a back plate **236** that includes a centrally disposed annular pole piece **238**, for providing a permanent magnetic field in the gap (see FIG. **3** and related description below) between the pole piece **238** and an inside surface of the annular top plate **234** for electrodynamic coupling with a voice coil (described below and illustrated in FIG. **3**). In the example illustrated in FIG. **2**, the diaphragm **208** is configured as an annular ring that is disposed coaxially with the central axis **112**. In other implementations, however, the diaphragm **208** may have other suitable configurations such as a dome or a cone. The compression driver **204** may also include a phasing plug assembly **240** that comprises the housing **120** and a phasing plug **244** generally disposed within the housing **120**. The body of the phasing plug **244** may include a base portion **250** and a central or hub portion **254**, both of which are coaxially disposed about the central axis **112**. The hub portion **254** may also be referred to as a bullet. The base portion **250** generally includes a first or input side **274** generally facing the diaphragm **208**, and an opposing second or output side **278** generally facing the interior of the housing **120**. The base portion **250** may further include one or more apertures (described below and illustrated in FIGS. **4-6** and **9**) that extend as channels or passages through the thickness of the base portion **250** from the input side **274** to the output side **278**.

FIG. **3** is an exploded cross-sectional view of the compression driver **204** illustrating additional components and features that may be provided. The compression driver **204** additionally includes a magnet or voice coil **304** for producing the movement of the flexible portion of the diaphragm **208** and a structural member such as a coil former **308** for supporting the voice coil **304**. The diaphragm **208** may include a profiled section such as a V-shaped section **312** having a circular apex **316** coaxial with the central axis **112**. The voice coil **304** or the former **308** may be attached to the diaphragm **208** at the apex **316** to facilitate actuation of the diaphragm **208** by the voice coil **304**. The compression driver **204** may also include the afore-mentioned annular top plate **234** and back plate **236**. The pole piece **238**, which may be integrated with the back plate **236**, may include a central bore **326**. The top plate **234** and outer magnet **232** on the one side and the pole piece **238** on the other side cooperatively define a magnetic or air gap **328**. In the assembled form of the compression driver **204** (see FIG. **9**), the voice coil **304** and coil former **308** are disposed in this gap **328** such that the voice coil **304** is immersed in a magnetic field, and the gap **328** provides axial spacing through which the voice coil **304** may oscillate. It can be seen that upon assembly of the compression driver **204**, a compression chamber is defined in a spacing **332** between the diaphragm **208** and the input side **274** of the base portion **250** (see also FIG. **9** and related description below). In practice, the height of the compression chamber (i.e., the distance between the diaphragm **208** and the input side **274** of the base portion **250**) may be quite small (e.g., approximately 0.5 mm or less) such that the volume of the compression chamber is also small. In implementations where the diaphragm **208** includes a V-shaped section **312**, the base portion **250** at the input side **274** may also include a complementary V-shaped section **336** (or other type of profiled section) positioned in general alignment with the V-shaped section **312** to maintain the small volume of the compression chamber.

As described in more detail below, the hub portion **254** of the phasing plug **244** generally includes one or more outer surfaces **340** and the housing **120** includes an inner surface **344**. After assembly of the phasing plug assembly **240**, the outer surface **340** and inner surface **344** cooperatively define a waveguide **348** for the propagation of sound waves through the phasing plug assembly **240**. The waveguide **348** terminates at an outlet **352** of the phasing plug assembly **240** (which, in the present example, is defined primarily by the structure of the housing **120** at the output end **132**) such that the waveguide **348** fluidly communicates with the interior **128** of the horn **108** if provided (FIG. **1**). The horn **108** may also be considered to be a waveguide in that sound energy radiates through the horn **108** and is constrained by the structure **124** of the horn **108** that shapes its interior **128**.

FIG. **4** is a perspective view of the phasing plug **244** that may be located in the transducer section **104** of the loudspeaker **100** (FIG. **1**) and assembled with the housing **120** as shown in FIGS. **2** and **3**. Specifically, FIG. **4** illustrates the phasing plug **244** from the perspective of its input side **274**, i.e., the side on which the diaphragm **208** and compression chamber of the compression driver **204** may be located (see FIGS. **2** and **3**). The phasing plug **244** may include a mounting feature **404** on the input side **274** that depends downwardly from the base portion **250**. The mounting feature **404** may have any configuration suitable for coupling the phasing plug **244** to the rear section **116** of the loudspeaker **100** (FIG. **1**). In the illustrated example, the mounting feature **404** is provided in the form of a segmented cylinder that is adapted to be press-fitted into the central bore **326** formed in the pole piece **238** or back plate **236** (FIG. **3**; see also FIG. **9**). As illustrated in FIG. **4**, the base portion **250** of the phasing plug **244** may be generally circular or may have any other suitable geometry.

As additionally illustrated in FIG. **4** and as previously described, one or more apertures may be formed through the thickness of the base portion **250** through which sound energy may travel from the input side **274** to the opposing output side **278** (FIGS. **2** and **3**) of the base portion **250**. For example, the base portion **250** may include one or more first or inner apertures **412** and one or more second or outer apertures **416**. When more than one aperture **412** or **416** is employed, the resulting plurality of apertures **412** or **416** may be circumferentially spaced from each other relative to the central axis **112**. Moreover, each aperture **412** or **416** may have a dominant dimension (e.g., length, width, etc.) in one direction such that each aperture **412** or **416** may be characterized as a slot or slit. The dominant dimension may be arcuate such that each aperture **412** or **416** may be formed as a circular segment. In other implementations, the apertures **412** or **416** may have a dominant dimension in the radial direction relative to the central axis **112**, in which case the apertures **412** or **416** may be characterized as radial slots. In still other implementations, no one dimension of the apertures **412** or **416** may be substantially dominant, such that the apertures **412** or **416** are more rectilinear-shaped as compared to the implementation illustrated in FIG. **4** (see, e.g., FIG. **12**).

Moreover, as specifically illustrated in the example provided in FIG. **4**, some or all apertures of the phasing plug **244** may be grouped in one or more segmented, concentric circles relative to the central axis **112**. For example, one circumferential set of apertures **412** may be located at a first radius from the central axis **112**, another circumferential set of apertures **416** may be located at a second, greater radius from the central axis **112**, and additional apertures (not shown) may be located at different (greater and/or lesser) radii. Some or all of the apertures **412** and **416** may be located at the V-shaped section **336** of the input side **278** of the base portion **250**. As also illustrated by way of example in FIG. **4**, the respective angles at which the apertures **412** and **416** are oriented at the sides of the V-shaped section **336** may be continued through the thickness of the base portion **250**, such that the apertures **412** and **416** (and hence the air paths defined by the apertures **412** and **416**) converge towards each other as they approach the side of the base portion **250** opposite to the input side **274** (see FIG. **9**). Corresponding pairs of inner apertures **412** and outer apertures **416** may be circumferentially separated by solid bridge sections **420** of the base portion **250**. The bridge sections **420** may also serve to hold separate parts of the phasing plug **244** together and thus provide mechanical integrity for the phasing plug **244**.

As in the case of any compression driver, an important parameter of the compression driver **204** illustrated in this disclosure is its compression ratio, which is determined from the relationship between the effective area of the diaphragm **208** (FIGS. **2** and **3**) and the effective area of the entrance into the phasing plug **244**. In the implementation illustrated by way of example in FIGS. **2** and **3**, the effective area of the diaphragm **208** is the portion of the diaphragm **208** that serves as a boundary of, and hence at least partially defines, the compression chamber. As illustrated in FIG. **4**, the effective area of the entrance into the phasing plug **244** is the total cross-sectional area of all apertures **412** and **416** of the base portion **250** at the input side **274**. The compression ratio affects the efficiency of the compression driver **204** and influences the shape of the frequency response. Therefore, the dimensions of the apertures **412** and **416** of the phasing plug **244** and the dimensions of the bridge sections **420** between the apertures **412** and **416** are variables that control the compression ratio.

In addition, the radial positions of the apertures **412** and **416** relative to the central axis **112** determine the shape of the frequency response of the compression driver **204** at high frequencies, because the apertures **412** and **416** may suppress the high-frequency standing waves that may occur in a radial direction within the compression chamber. The use of several concentrically positioned apertures **412** and **416** provides shorter paths for sound waves traveling from the peripheral, circumferential boundaries of the compression chamber to the nearest apertures **412** or **416**. As the height of the compression chamber may be merely a fraction of a millimeter, viscous resistive losses in the air may affect frequency response if the path of a sound wave in a radial direction is long. Accordingly, the use of several apertures **412** and **416** as illustrated in FIG. **4** shortens the radial path and provides a favorable condition for the propagation of sound waves without significant losses. Furthermore, the use of several apertures **412** and **416** may be desirable because a single aperture may not be sufficient to suppress undesirable resonances.

In addition, while the size (i.e., dimensions) of the apertures **412** and **416** should be selected so as to attain the desired compression ratio, the apertures **412** and **416**—particularly when shaped as slots or other narrow shapes—should not be so narrow as to adversely affect maintaining proper, repeatable tolerances during manufacture. Moreover, the use of excessively narrow or restrictive apertures **412** and **416** may adversely affect the reproduction of high-frequency audio signals due to the introduction of viscous, resistive losses. Therefore, all such factors should be weighed in sizing the apertures **412** and **416**. In some implementations, the size of the apertures **412** and **416** is optimized by maintaining a width (i.e., the long dimension) of, for instance, approximately 1 mm or greater. As noted previously, the width of the apertures **412** and **416** and thus the compression ratio may be controlled by controlling the width and number of the bridge sections **420** between the apertures **412** and **416**.

FIG. **5** is a perspective view of the phasing plug **244** from the perspective of the output side **278** of the phasing plug **244** on which the horn **108** (FIG. **1**) may be located, i.e., the side of the base portion **250** opposite to the input side **274** where sound waves are produced. By way of example in FIG. **5**, the apertures **412** and **416** may converge toward each other until they terminate at the output side **278**, where each corresponding pair of inner apertures **282** and outer apertures **312** is separated by an edge or landing **504**. Like the apertures **412** and **416**, each edge **504** may be arcuate such that the edges **504** comprise circular segments. On the output side **278**, adjacent edges **504** as well as corresponding pairs of inner apertures **282** and outer apertures **312** may be circumferentially separated by the bridge sections **420** of the base portion **250**.

As also illustrated in FIG. **5** and as noted previously, the phasing plug **244** may include a central or hub portion **254**, which may also be referred to as a bullet. The hub portion **254** may be integrally formed with the base portion **250** in a suitable fabrication process, or may be attached to the base portion **250** by any suitable means. The hub portion **254** has a first or proximal end **512** disposed proximate to the base portion **250** and a second or distal end **516** disposed at a distance from the base portion **250** along the central axis **112**. From the perspective of FIG. **5**, the hub portion **254** extends upwardly from the base portion **250** generally along the central axis **112** from the first end **512** to the second end **516**. As previously noted, the outer profile of the hub portion **254**, or the radial profile relative to the central axis **112**, may be defined by one or more outer surfaces **340**. In some implementations, the hub portion **254** is axisymmetrical about the central axis **112** and its cross-section perpendicular to the central axis **112** is generally circular, such that the outer profile of the hub portion **254** may be defined essentially by a single outer surface **340** swept about the central axis **112**. The outer surface **340** may taper in the direction along the central axis **112** from the first end **512** to the second end **516**, such that the radius of the cross-section of the hub portion **254** relative to the central axis **112** decreases in this direction as illustrated in FIG. **5**. In such an implementation, the radius of the outer surface **340** at the first end **512** is greater than the radius of the outer surface **340** at the second end **516**. Moreover, in some implementations such as illustrated in FIG. **5**, the radius of the outer surface **340** at the first end **512** is the maximum radius and the radius of the outer surface **340** at the second end **516** is the minimum radius. In some implementations, the second end **516** terminates at a point or edge, while in other implementations the second end **516** is rounded or domed. In either case, the distal-most portion of the second end **516** may be an apex at which the radius is essentially zero, or coincident with the central axis **112**.

In some implementations such as illustrated in FIG. **5**, the hub portion **254** (or at least its outer surface **340**) may be considered as including two or more sections, with adjacent sections preferably transitioning into each other smoothly without any sharp features or discontinuities. In the example given in FIG. **5**, the hub portion **254** includes a first section **524** that transitions into a second section **528**. The first section **524** may be convex, or curve (or bulge) outwardly, relative to the central axis **112**, and the second section **528** may be concave, or curve (or bulge) inwardly, relative to the central axis **112**. The second end **516** of the hub portion **254**, if rounded or domed, may be considered a third section **532**, which may be convex relative to the central axis **112**. In some implementations, the outer surface **340** of the hub portion **254** may be characterized as being shaped as a "candy kiss." One function of the hub portion **254** is to partially define the enclosed area or waveguide **348** (FIG. **3**) through which sound energy exiting from apertures **412** and **416** travels. Accordingly, as illustrated in FIG. **5**, the radius of the outer surface **340** of the hub portion **254** at the first end **512** is less than or approximately equal to the radius of the innermost circumferential group of apertures **412**.

As further illustrated in FIG. **5**, the hub portion **254** may include a plurality of protruding elements such as ribs **536** disposed on the outer surface **340**. The ribs **536** may extend generally in a resultant direction from the first end **512** of the hub portion **254** toward the second end **516**, and may traverse over a portion of the outer surface **340** as illustrated or may traverse the entire outer surface **340** up to or near the second end **516**. Each rib **536** includes a first or proximal end **540** disposed proximate to the base portion **250** and a second or distal end **544** disposed at a distance from the base portion **250** along the central axis **112**. In some implementations, as illustrated in FIG. **5**, the first end **540** of each rib **536** begins at or near a corresponding one of the bridge sections **420** of the base portion **250**, such that each pair of inner apertures **412** and outer apertures **416** is interposed between adjacent first ends **540**. Each rib **536** may protrude radially outwardly from the outer surface **340** of the hub portion **254** to an outer surface **548** of the rib **536**, and hence each rib **536** may include two opposing side walls **552** and **556** on either side of its outer surface **548**. The circumferential width of each rib **536** (e.g., the width of each outer surface **548**) may be uniform or substantially uniform along its length as illustrated in FIG. **5**, or this width may vary or taper. The side walls **552** and **556** of each rib **536** determine the radial thickness or height of the rib **536** between the outer surface **340** of the hub portion **254** and the outer surface **548** of the rib **536**, i.e., the amount by which the rib **536** protrudes from the outer surface **340** of the hub portion **254** at any given location. This radial thickness of the rib **536** may vary or taper generally in the direction along the central axis **112** from the first end **540** to the second end **544** of each rib **536**, such that the radial thickness decreases in this direction as illustrated in FIG. **5**. In such an implementation, the radial thickness of each rib **536** at the first end **540** is greater than the radial thickness at the second end **544**. Moreover, in some implementations such as illustrated in FIG. **5**, the radial thickness of each rib **536** at the first end **540** is the maximum radial thickness and the radial thickness of each rib **536** at the second end **544** is the minimum radial thickness. In some implementations, the second end **544** of each rib **536** is flush or substantially flush with the outer surface **340** of the hub portion **254**, such that the radial thickness of each rib **536** at the second end **544** is reduced to zero or approximately zero and each rib **536** gradually merges into the outer surface **340** of the hub portion **254**. The outer profile of each rib **536**, defined generally by the outer surface **548**, may be shaped similarly to the outer profile of the hub portion **254** or otherwise follow the outer profile of the hub portion **254**. Accordingly, in some implementations such as the example illustrated in FIG. **5**, the portion of each rib **536** immediately adjacent to the outwardly bulging first section **524** of the hub portion **254** may also bulge outwardly.

In the example illustrated in FIG. **5**, the side walls **556** and **552** that face each other between any two adjacent ribs **536**, and the outer surface **340** of the hub portion **254** between the same two adjacent ribs **536**, cooperatively define a pocket or recess **560** that begins at the base portion **250** where the apertures **412** and **416** are located and ends generally at the second ends **544** of the adjacent ribs **536**. Accordingly, in this example, a plurality of pockets or recesses **560** are defined between each pair of adjacent ribs **536**, with the number of recesses **560** corresponding to the number of apertures **412** or **416** or pairs of inner apertures **412** and outer apertures **416**. Each recess **560** is defined in part by a circumferential width or spacing between adjacent ribs **536**. As illustrated in FIG. **5**, due to the tapering outer profile of the hub portion **254**, the circumferential width of each recess **560** may likewise taper in a decreasing manner generally in the axial direction from the first ends **540** of the ribs **536** to the second ends **544**. It can be seen that when the phasing plug **244** is assembled with the housing **120** as shown, for example, in FIG. **3**, the recesses **560** may be considered as being part of the resulting waveguide **348**, with the recesses **560** beginning at the apertures **412** and **416** on the output side **278** of the phasing plug **244** and transitioning into the remaining portion of the waveguide **348**. As discussed further below, this configuration advantageously provides a continuous, gradual area of expansion for the propagation of sound waves.

FIG. **6** is a perspective exploded view illustrating the phasing plug **244** in axial alignment with the housing **120** prior to assembly. As previously noted, the housing **120** generally includes an input end **128** that in assembly is located proximate to the base portion **250** of the phasing plug **244**, and an output end **132** that is disposed at a distance from the first end **128** along the central axis **112**. In addition to the previously noted inside surface **344**, the housing **120** may include an outside surface **604**, a flange portion **608**, an upper portion **612**, and a generally frustoconical intermediate portion **616** interposed between the flange portion **608** and the upper portion **612**. The upper portion **612** may be generally cylindrical as illustrated in this example. The flange portion **608** may be adapted to fit onto, and wholly or partially enclose, the base portion **250** of the phasing plug **244**. The inside surface **344** encloses an interior of the housing **120** to form a waveguide **348** as illustrated in FIG. **3**. The inside surface **344** may be shaped to provide the waveguide **348** with an expanding cross-sectional area for sound propagation. The inside surface **344** may be shaped to accommodate a typical implementation in which apertures such as apertures **412** and **416** are located at a diameter relative to the central axis **112** that is greater than the diameter of the driver exit at the output end **132**.

FIG. **7** is a cut-away exploded view illustrating the phasing plug **244** in axial alignment with the housing **120** prior to assembly. In this example, the inside surface **344** of the housing **120** may include a base or entrance section **704** at the first end **128**. The base section **704** transitions to a tapered section **708**, and the tapered section **708** in turn transitions to an upper section **712**. The upper section **712** may be cylindrical or substantially cylindrical as illustrated in this example, or may have another suitable profile such as conical. The inside surface **344** in the upper section **712** terminates at the second end **132** of the housing **120**, where the inside surface **344** defines the outlet **352** of the housing **120**. To accommodate the insertion of the hub portion **254** of the phasing plug **244** into the interior of the housing **120** and to establish the beginning of the waveguide **348**, the radius of the inside surface **344** of the housing **120** at its entrance section **704** relative to the central axis **112** is greater than the radius of the ribs **536** (FIGS. **5** and **6**) of the hub portion **254** of the phasing plug **244** and is large enough to enclose all apertures **412** and **416** (FIG. **5**) on the output side **278** of the phasing plug **244**. The tapered section **708** of the inside surface **344** of the housing **120** may be tapered generally in the direction from the first end **128** toward the second end **132**, such that the radius of the inside surface **344** in the tapered section **708** relative to the central axis **112** decreases along this direction. The radius of the inside surface **344** of the housing **120** in the upper section **712** may be uniform or substantially uniform.

FIG. **8** is a cut-away view illustrating the housing **120** assembled concentrically with the phasing plug **244** to form an implementation of the phasing plug assembly **240**. When so assembled, the inside surface **344** of the housing **120** and the respective outer surfaces **340** and **548** of the hub portion **254** and ribs **536** cooperatively define the waveguide **348** of the phasing plug assembly **240** for propagating sound waves emanating from the exit sides of the apertures **412** and **416** (FIG. **5**) of the phasing plug **244**. From the perspective of FIG. **8**, the exit sides of the apertures **412** and **416** of the phasing plug **244** are located at the planar elevation or level generally indicated by an arrow **804**, which also designates the beginning or input end of the waveguide **348**. That is, the input end **804** of the waveguide **348** is an annulus of relatively small cross-sectional area. In the example illustrated in FIG. **8**, it can be seen that the curves defining the various sections of the outer surface **340** of the hub portion **254** (e.g., the first section **524**, second section **528**, and third section **532**), as well as the outer surfaces **548** of the ribs **536**, may be different than the curves defining the various sections of the inside surface **344** of the housing **120** (e.g., the base section **704**, tapered section **708**, and upper section **712**). The respective cross-sectional profiles of the outer surfaces **340** and **548** of the hub portion **254** and ribs **536** and the inside surface **344** of the housing **120** may be configured such that cross-sectional area (orthogonal to the central axis **112**) of the resulting waveguide **348** exhibits a progressive expansion for the propagation of sound waves. The waveguide **348** may be considered as ending at the outlet **352**, at which the cross-sectional area of the waveguide **348** may be a maximum. The cross-sectional area of the waveguide **348** may be annular up to the end **516** of the hub portion **254**. As previously noted in conjunction with the loudspeaker **100** illustrated in FIG. **1**, the waveguide **348** may effectively be extended through the use of a horn **108**.

FIG. **9** is a perspective cross-sectional view of the compression driver **204** in assembled form. An annular compression chamber **902** is defined between the diaphragm **208** and the input side **274** of the phasing plug **244**. As previously noted, the spacing between the diaphragm **208** and the input side **274** of the phasing plug **244** is typically small (e.g., approximately 0.5 mm or less) such that the volume of the compression chamber **902** is likewise small. FIG. **9** illustrates the pathways through which sound may travel in the compression driver **204**. As can be appreciated by persons skilled in the art, the actuation of the diaphragm **208** generates high sound-pressure acoustical signals within the compression chamber **902**, and the signals travel as sound waves through the base portion **250** via the apertures **412** and **416** that provide passages from the input side **274** to the output side **278**. From the apertures **412** and **416**, the sound waves enter and radiate through the waveguide **348** of the phasing plug assembly **240** to the outlet **352**. If a horn **108** (FIG. **1**) is provided, the sound waves travel through the interior **128** of horn **108**, which effectively extends the waveguide **348**, and propagate into the ambient environment from the mouth **140**. Referring also to FIGS. **5**, **6**, and **8**, it can be seen that in the section of the waveguide **348** where the ribs **536** are located on the hub portion **254**, i.e., near the exit side of the phasing plug **244**, most of the volume available for the propagation of sound waves is provided by the recesses **560** interposed between adjacent ribs **536**. By means of their protruding thicknesses, the ribs **536** control the area of expansion until the ribs **536** merge into the hub portion **254**, at which point the recesses **560** transition into the remaining (or upper) portion of the waveguide **348**.

Referring primarily to FIGS. **5**, **6**, **8** and **9**, the utilization of ribs **536**—or, stated alternatively, the utilization of recesses **560** between the ribs **536**—on the outer surface **340** of the hub portion **254** provides advantages. Considering that the waveguide **348** defined by the phasing plug assembly **240** essentially begins with the plurality of apertures **412** and **416** in the phasing plug **244**, it can be appreciated that without the ribs **536** (or recesses **560** between the ribs **536**), the total cross-sectional area for sound propagation would abruptly change at the exit side of the apertures **412** and **416**, i.e., at the interface of the apertures **412** and **416** and waveguide **348** defined between the inside surface **344** of the housing **120** and the outer surface **340** of the hub portion **254**. This abrupt change would result from the fact that, at this interface, the bridge sections **420** between the apertures **412** and **416** no longer exist, at which point the cross-sectional area would change from being the total area of the apertures **412** and **416** to being all of the annular area between the inside surface **344** and the outer surface **340**. Conversely, in implementations such as illustrated by way of example in this disclosure, the provision of the ribs **536** (and the recesses **560** between the ribs **536**) enables the utilization of a plurality of apertures **412** and **416** and a phasing plug **244** with a hub portion **254** with all of the attendant advantages but without a disadvantageous abrupt change in cross-sectional area. That is, the presence of the ribs **536** and recesses **560** provide a gradual, controlled transition for sound propagation from the apertures **412** and **416** of the phasing plug **244** to the waveguide **348** of the phasing plug assembly **240**, and further provide a gradual and continuous (or substantially continuous) expansion in the cross-sectional area of the waveguide **348** from the compression chamber to the outlet **352** of the phasing plug assembly **240**. This configuration improves the flatness of the frequency response and prevents undesirable perturbations of sound waves conventionally caused by discontinuities of the expansion area.

FIGS. **10-12** illustrate a phasing plug assembly **1002** according to alternative implementations. Specifically, FIG. **10** is a perspective view of the phasing plug assembly **1002** from the perspective of the top of the housing **120**. The phasing plug assembly **1002** includes a phasing plug **1006** that includes a base portion **1010** and a hub portion **1014**. In this example, the hub portion **1014** has an outer surface **1018** that is conical and terminates at an end or tip **1022**. The hub portion **1014** includes a plurality of ribs **1024** protruding from the outer surface **1018**, with pockets or recesses **1030** formed between adjacent ribs **1024**. Each rib **1024** has two opposing side walls **1034** and **1038**. As in the previously described implementation (see, e.g., FIG. **5**), the radial thickness of each rib **1024** (i.e., the amount by which the rib **1024** protrudes outwardly from the outer surface **1018** of the hub portion **1014**) tapers along the length of the rib **1024** in a direction generally from the base portion **1010** toward the tip **1022** of the hub portion **1014**. Accordingly, the radial thickness of each rib **1024** decreases until the rib **1024** essentially merges into the outer surface **1018** of the hub portion **1014** at an end **1042** of the rib **1024**. Additionally, in this example, the circumferential width of each rib **1024** (e.g., the width between the two opposing side walls **1034** and **1038**) tapers along the length of the rib **1024** in the direction generally from the base portion **1010** toward the tip **1022** of the hub portion **1014**, such that the end **1042** of each rib **1024** may be pointed. As also illustrated in FIG. **9**, the recesses **1030** are deeper as compared with those illustrated in FIG. **5** to accommodate apertures **1046** of larger cross-sectional area.

FIG. **11** is a perspective cut-away view of the phasing plug assembly **1002**. In this example, the base portion **1010** includes an input side **1102** that is adapted to accommodate a dome-shaped diaphragm (not shown). Accordingly, at least a portion of the input side **1102** is likewise dome-shaped. It can be envisioned in this example that the compression chamber defined between the diaphragm and the input side **1102** would likewise have a dome-shaped volume. It can also be envisioned that the input side **1102** could be modified to accommodate other shapes of diaphragms such conical and frustoconical shapes.

FIG. **12** is a perspective view of the phasing plug assembly **1002** from the perspective of the bottom of the base portion **1010**. In this example, a single group of circumferentially positioned apertures **1046** are provided in the dome-shaped portion of the input side **1102**. The apertures **1046** are more square-shaped as compared with those illustrated in FIGS. **4-6**. Adjacent apertures **1046** are separated by solid bridge sections **1202**. It can be seen that if the number of apertures **1046** (and thus bridge sections **1202**) are increased in this group or, alternatively, if the circumferential dimensions of the apertures **1046** are increased, then the radial dimension of the apertures **1046** (relative to the center of the phasing plug assembly **1002**) would become the dominant dimension such that the apertures **1046** could be characterized as radial slots or slits.

FIGS. **13** and **14** are perspective views of a phasing plug **1302** according to another implementation. In this example, the phasing plug **1302** has a first section or base portion **1306** that has a plurality of radial apertures or slots **1310**. The apertures **1310** are separated by solid bridge sections **1314**. The phasing plug **1302** includes an outer surface **1318** and a plurality of ribs **1322** protruding outwardly from the outer surface **1318**. Each rib **1322** has a first end **1326** at the base of the phasing plug **1302** and a second end **1330**. The thickness of each rib **1322** may taper such that the second end **1330** merges into the outer surface **1318**. A plurality of pockets or recesses **1334** are defined between corresponding pairs of adjacent ribs **1322**, and begin at the first ends **1326** of the ribs **1322**. In the example illustrated in FIGS. **13** and **14**, the width of the recesses **1334** (i.e., the distance between pairs of adjacent ribs **1322**) is the same or substantially the same as the width of the apertures **1310**. When utilized in a compression driver, this configuration provides an uninterrupted area of expansion through which sound waves propagate. The phasing plug **1302** illustrated in FIGS. **13** and **14** may be utilized in conjunction with any type of diaphragm (annular, domed, conical, or the like) provided in a compression driver. It will be understood that a separate base portion (not shown) may be provided at the base of the phasing plug **1302**, in which case the structure illustrated in FIGS. **13** and **14** may be characterized as being the hub portion of a phasing plug. The separate base portion may include radial apertures **1310** aligned with the radial apertures shown in FIGS. **13** and **14**.

It can thus be seen that the implementations disclosed herein offer significant flexibility in the specification of compression drivers for desired applications and frequency ranges in sound production. The compression ratio may be controlled by changing the width of the bridge sections and correspondingly the width of the ribs while, at the same time, preserving the continuity of the area of expansion defined by the waveguide of the phasing plug assembly. Accordingly, the implementations disclosed herein provide flexible control over efficiency of the compression driver and over the shape of its frequency response.

The foregoing description of implementations has been presented for purposes of illustration and description. It is not exhaustive and does not limit the claimed inventions to the precise form disclosed. Modifications and variations are possible in light of the above description or may be acquired from practicing the invention. The claims and their equivalents define the scope of the invention.

What is claimed is:

1. A phasing plug for a compression driver, comprising:

a base portion including a first side, a second side, and a plurality of apertures extending between the first and second sides; and

a hub portion extending from the base portion along a central axis of the phasing plug, the hub portion including an outer surface and a plurality of ribs disposed on the outer surface, where each rib includes a first end disposed proximate to the base portion and a second end disposed at a distance from the base portion, and each rib has a thickness by which the rib protrudes from the outer surface, where the thickness is greater at the first end than at the second end, where a plurality of recesses are defined by the outer surface and respective pairs of adjacent ribs, and where at least one aperture fluidly communicates with at least one of the recesses.

2. The phasing plug of claim **1**, where the plurality of apertures are each positioned at a radius from the central axis and are circumferentially spaced from each other.

3. The phasing plug of claim **1**, where the plurality of apertures include a plurality of sets of apertures, each set of apertures is positioned at a radius from the central axis different from the other sets of apertures, and in each set the apertures are circumferentially spaced from each other.

4. The phasing plug of claim **1** comprising a plurality of bridge sections, each bridge section interposed between a pair of adjacent apertures.

5. The phasing plug of claim **4**, where each rib includes an end disposed at a respective bridge section.

6. The phasing plug of claim **1**, where the hub portion includes a proximal end disposed proximate to the base portion and a distal end disposed at a distance from the base portion, and a radius of the outer surface from the central axis at the proximal end is greater than a radius of the outer surface at the distal end.

7. The phasing plug of claim **6**, where the radius of the outer surface decreases from the proximal end to the distal end, and the outer surface has a curved profile substantially free of discontinuities between the proximal end and the distal end.

8. The phasing plug of claim **1**, where the thickness decreases from the first end to the second end, and the rib has a curved outer profile substantially free of discontinuities between the first end and the second end.

9. The phasing plug of claim **8** where, at the second end, the thickness is reduced such that the rib substantially merges into the outer surface.

10. The phasing plug of claim **1**, where the hub portion is substantially axisymmetrical about the central axis.

11. The phasing plug of claim **1**, where the base portion includes a plurality of bridge sections, each bridge section interposed between a pair of adjacent apertures, each rib includes a rib end disposed at a respective bridge section, and each aperture fluidly communicates with at least one of the recesses.

12. The phasing plug of claim **1**, where the apertures are shaped as radial slots.

13. The phasing plug of claim **1**, where the apertures are substantially rectilinear-shaped.

14. A phasing plug for a compression driver, comprising:

a housing including an inner surface defining an interior and an outlet;

a base portion including a first side, an opposing second side generally facing the interior, a plurality of apertures extending between the first and second sides, and a plurality of bridge sections, each bridge section interposed between a corresponding pair of adjacent apertures; and

a hub portion extending from the base portion into the housing along a central axis of the phasing plug, the hub portion including an outer surface disposed coaxially about the central axis and a plurality of ribs extending from the outer surface, each rib including a first rib end disposed at a corresponding bridge section and a second rib end disposed at a distance from the first rib end, and each rib protruding from the outer surface with a thickness, where the thickness gradually reduces from the first rib end towards the second rib end.

15. The phasing plug of claim **14**, where the inner surface and outer surface cooperatively define a waveguide, and are shaped so that the cross-sectional area of the waveguide expands along the central axis from the plurality of apertures to the outlet, and in the portion of the waveguide proximate to the apertures the expansion of the cross-sectional area is controlled by the ribs.

16. The phasing plug of claim **15**, where the hub portion includes a proximal end disposed proximate to the base portion and a distal end disposed at a distance from the base portion, and the radius of the outer surface relative to the central axis decreases from the proximal end to the distal end.

17. The phasing plug of claim **14** where, at the second rib end, the thickness is reduced such that the rib substantially merges into the outer surface.

18. The phasing plug of claim **17**, where the second rib end is disposed at an axial distance from the outlet.

19. The phasing plug of claim **14**, where the plurality of apertures include a first set of apertures positioned at a first radius from the central axis and a second set of apertures positioned at a second radius from the central axis, each aperture of the first set is radially aligned with a respective aperture of the second set relative to the central axis, and each pair of radially aligned apertures fluidly communicates with a respective recess.

20. A compression driver comprising:

a housing including an inner surface at least partially defining an interior of the housing and an inlet;

a phasing plug disposed in the housing;

a diaphragm coupled to the inlet of the housing;

a compression chamber defined between the diaphragm and the phasing plug, where the phasing plug includes a plurality of apertures providing a plurality of respective fluid passages from the compression chamber to the housing interior; and

a hub portion disposed in the interior and including an outer surface, a plurality of ribs protruding outwardly from the outer surface, and a plurality of recesses interposed between respective pairs of adjacent ribs, where each rib among the ribs comprises a first end disposed proximate to the apertures and a second end disposed at a distance from the apertures, and where a thickness of each rib tapers from the first end towards the second end, and each aperture among the apertures fluidly communicates with at least one of the recesses.

21. The compression driver of claim **20**, where the phasing plug includes a plurality of bridge sections, each bridge section is interposed between a pair of adjacent apertures, and each rib includes a rib end disposed at a respective bridge section.

22. The compression driver of claim **20**, where the housing includes an outlet, the outer surface and at least a portion of the inner surface cooperatively define a wave guide generally extending from the apertures to the outlet, and at least a portion of the waveguide proximate to the apertures is further defined by the recesses.

23. The compression driver of claim **20**, where the hub portion includes a proximal end disposed proximate to the apertures and a distal end disposed at a distance from the apertures, and a radius of the outer surface relative to an axis decreases from the proximal end to the distal end.

24. The compression driver of claim **20** comprising a horn, where the housing includes an outlet fluidly communicating with the horn.

25. The phasing plug of claim **14**, where a plurality of recesses are respectively defined between pairs of adjacent ribs, each aperture provides communication with at least one recess, the inner surface and the outer surface cooperatively define a waveguide generally extending from the apertures to the outlet, and at least a portion of the waveguide proximate to the apertures is further defined by the recesses.

26. The compression driver of claim **20**, where a depth of each recess among the recesses tapers along an axis from the first end of the respective pair of adjacent ribs towards the second end of the respective pair of adjacent ribs.

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