Dynamics of Bass-Reflex Loudspeaker Systems(2)

Classification of Bass-Reflex Loudspeaker Systems

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Released on May 24th, 2008 in Japanese

Released on Feb. 27, 2011 in English

1. Preface

Bass-Reflex is one of the most practical enclosure and it has been widely used for loudspeaker systems. Most of this application is single bass-reflex enclosure. Some amateur engineers use double bass-reflex enclosure, but it is not major in the industry.

Reasons why double-bass-reflex system is not widely used will not be patent reasons but the followings:

Enclosure size tend to be big

Best design scheme is not found.

Tetsuo Nagaoka stated that double-bassleflex was too complex to analyze precisely in his publication[1].

My focus is not to discuss if one feels the sound good or bad but technical feasibility of multiple degree of freedom (MDOF) bass-reflex or cavity resonator applications. Mathematical model of bass-reflex is series of discretized equation. It is not difficult to simulate move of discrete masses, since equations are linear. I think it is myth to believe that MDOF bass-reflex system is difficult to design.

Because of this myth, enough research was not done over MDOF bass-reflex systems. I decided to write this paper to show that MDOF bass-reflex system is not too difficult to analyze. This paper will prove that MDOF bass-reflex systems are practical enough to develop reasonable applications.

1 長岡鉄男”、長岡鉄男のオリジナルスピーカー設計術　こんなスピーカー見たことない”、音楽之友社、1996

2. Classification of Bass-Reflex Loudspeaker Systems

Bass-Reflex Loudspeaker system is an application of Helmholtz's cavity resonator. Theory of cavity resonator is explained in any physics textbook. A simple cavity resonator consists of a closed chamber and a duct. One end of the duct is connected to the chamber and the other end is open to air. The chamber acts as air spring and the air in the duct acts as mass. This configuration realizes resonant vibration system. This is also explained in MCAP001E.

Since bass-reflex system consists of only mass(es) and chamber(s), there are a number of configurations. We classify configurations of masses and chambers and find equation of motion for each typical configuration. Getting equations of motion, we could analyze move of masses.

Available studies about even single bass-reflex system is limited, there has been no classification of multiple degree of freedom cavity resonator systems. We

Table1 Classification of Cavity Resonator Loudspeaker Systems

Typical Application	Configuration	Note
Single Bass-Reflex	One chamber and one duct	Fig.1
Multiple-Chamber Aligned in Series Cavity Resonator (MCAS-CR)	Chambers,inter-chamber ducts and a duct open to air.	Fig.2 (Double Bass-Reflex) - Fig.3
Multiple-Chamber Aligned in Parallel Cavity Resonator (MCAP-CR)	Main chamber and multiple-chamber connected to main chamber through ducts. One or more chambers have open-air ducts.	Fig.4 MCAP-CR was developed by author.
Arbitrary Inter-Chamber Connection Cavity Resonator (AICC-CR)	Multiple-chamber and ducts chambers are arbitrarily connected through ducts. One or more ducts are open to air.	Fig.5 AICC-CR was proposed by author.

As far as I researched throughout web database, application's maximum number of chambers was three. Only two triple bass-reflex applications were found. I examined quadraple bass-reflex application in the past, but design was not good enough, so that good result was not got. There was no application or even concept of MCAP-CR.

We can derive equations of motion for every application given by Table 1. These applications are feasible.

2.1 Single Bass-Reflex and MCAS-CR

Fig.1 through Fig.3 shows configuration of single, double and MCAS-CR systems. k , circles, and zigzag line represents, respectively, spring constant, chambers, and coil spring of speaker driver. ● and x represents, respectively, mass and displacement of mass. Arrows define positive direction of mass' move. We let external force given to mass of membrane be $f(x)$.

Fig.2 illustrates double bass-reflex system. This is simple enough to design and manufacture. What is necessary for double bass-reflex is to establish calculation and design procedure. Fig.3 illustrates general MCAS-CR with n sub-chambers.

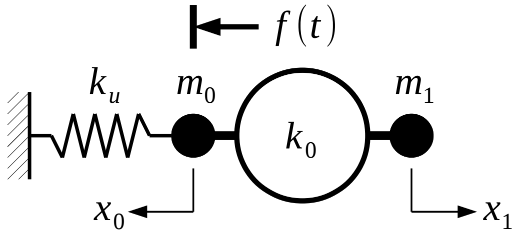

Fig.1 Single Bass-Reflex Model

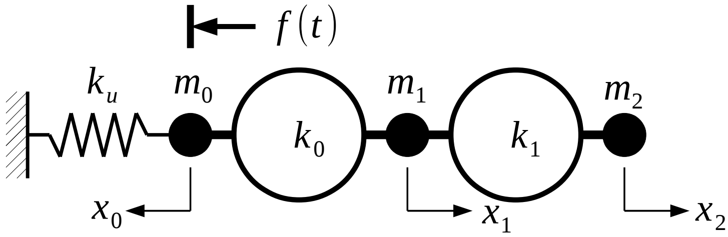

Fig.2 Double Bass-Reflex Model

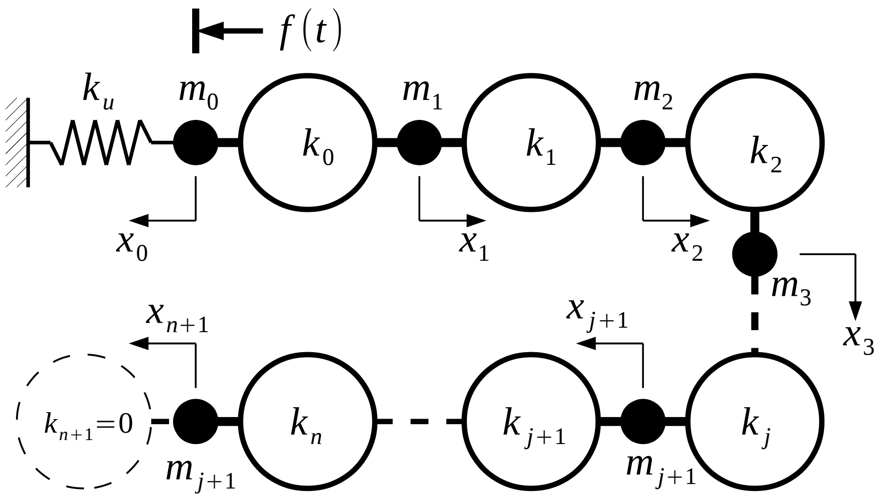

Fig.3 General MCAS-CR Model

For Fig.2 and Fig.3, it is not required to install speaker driver to install in chamber

k_0 . Speaker driver may be installed to any chamber. Characteristic frequencies of enclosure are not affected where driver is installed, but are affected if we consider mass m_0 . Then we need to modify equations of motion.

Fig.3 is MCAS-CR system with n chambers. It seems complex but not so much. MCAS-CR is just to add number of chambers to double-bass-reflex. There is “n+1” th chamber after last chamber. “n+1” th chamber is listening room and assumed much bigger than chambers so that stiffness of “n+1”th chamber $k_n=0$.

Equation of motion of each MCAS-CR is given in Table 2. These equations include mass of vibration membrane m_0 . Definitions of symbols are given in Table 3.

Table2 Equations of Motion of MCAS-CRs

Single Bass-Reflex $m_0\frac{d^2x_0}{dt^2}+(k_u+k_0)x_0+k_0r_1x_1=f(t)$ $m_1\frac{d^2x_1}{dt^2}+k_0r_1x_0+k_0r_1^2x_1=0$
Double Bass-Reflex $m_0\frac{d^2x_0}{dt^2}+(k_u+k_0)x_0+k_0r_1x_1=f(t)$ $m_1\frac{d^2x_1}{dt^2}+k_0r_1x_0+(k_0+k_1)r_1^2x_1-k_1r_1r_2x_2=0$ $m_2\frac{d^2x_2}{dt^2}-k_1r_1r_2x_1+k_1r_2^2x_2=0$
MCAS-CR with n Sub-Chambers $m_0\frac{d^2x_0}{dt^2}+(k_u+k_0)x_0+k_0r_1x_1=f(t)$ $m_1\frac{d^2x_1}{dt^2}+k_0r_1x_0+(k_0+k_1)r_1^2x_1-k_1r_1r_2x_2=0$ $m_2\frac{d^2x_2}{dt^2}-k_1r_1r_2x_1+(k_0+k_1)r_2^2x_1-k_2r_2r_3x_3=0$ $m_j\frac{d^2x_j}{dt^2}-k_{j-1}r_{j-1}x_{j-1}+(k_{j-1}+k_j)r_j^2x_j-k_jr_jr_{j+1}x_{j+1}=0$ $m_{n-1}\frac{d^2x_{n-1}}{d^2}t-k_{n-2}r_{n-2}x_{n-1}+(k_{n-2}+k_{n-1})r_{n-1}^2x_{n-1}-k_{n-1}r_{n-1}r_nx_n=0$ $m_n\frac{d^2m_n}{dt^2}-k_{n-1}r_{n-1}r_nx_{n-1}+(k_{n-1}+k_n)r_n^2x_n=0$

Table 3 Definitions of Symbols

Symbol	Definition	Note
a_0	Reference area $[m^2]$	Effective area of vibrating membrane
a_j	Cross-sectional area of each duct $[m^2]$	
r_j	Ratio of areas a_j/a_0	
m_j	Mass of bulk air involved in each duct $[g]$	
ρ	Density of air at room temperature $[kg/m^3]$	$\rho=1.2[kg/m^3]$
l_j	Effective length of each duct $[m]$	
P	Atmospheric pressure at room temperature $[Pa]$	$P=101{,}300[Pa]$
k_j	Spring constant of chamber for reference area $[N/m]$	$k_j=\frac{a_0^2 P}{V_j}[N/m]$
V_j	Volume of each chamber $[m^3]$	

2.2 Multiple Chamber Aligned in Parallel (MCAP-CR) system

MCAP-CR system had not been exist until I present the details. Therefore the name MCAP-CR is named by myself. Fig.4 shows the configuration of MCAP-CR. There are one main chamber, n sub-chambers and 2n ducts in Fig.4. Maximum number of eigen values is 2n+1, including mass of vibration membrane m_0 .

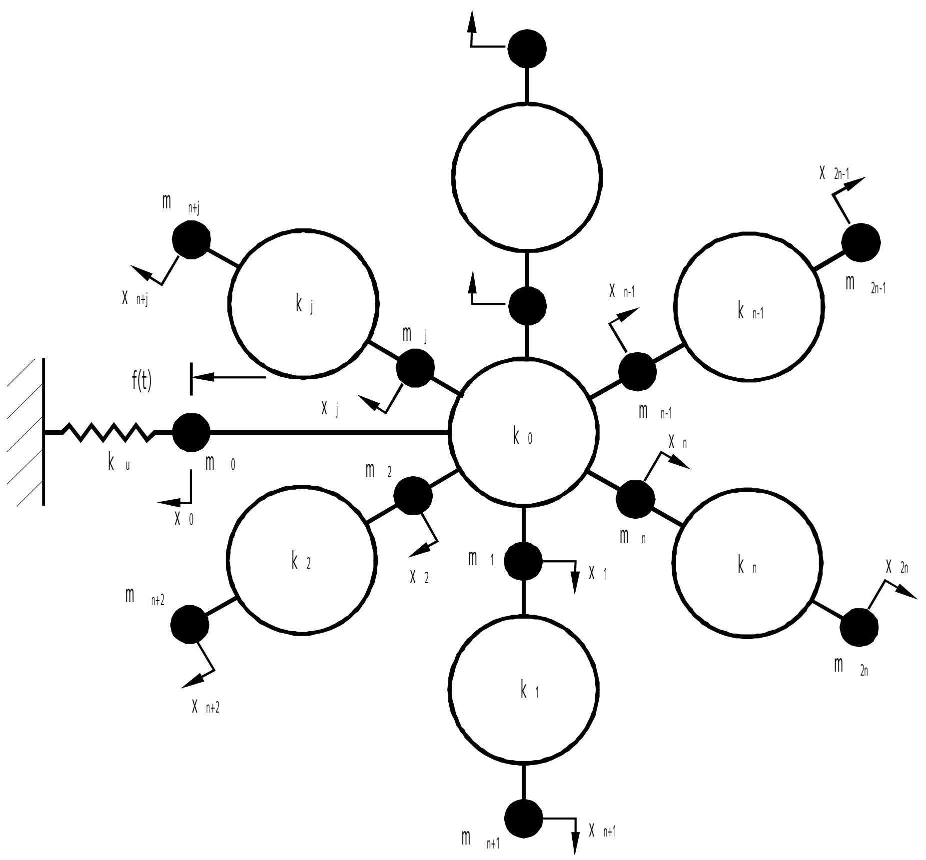

Fig.4 Multiple Parallel Bass-Reflex Model

Table4 gives equation of motion of Standard MCAP-CR.

Table 4 Equations of Motion of Standard MCAP-CR

$$m_0 \frac{d^2 x_0}{dt^2} + (k_u + k_0) r_0^2 x_0 + k_0 \sum_{i=1}^{n} r_0 r_i x_i = f(t)$$

.....

$$m_j \frac{d^2 x_j}{dt^2} + k_0 r_j \sum_{i=0}^{n} r_i x_i + k_j r_j (r_j x_j - r_{j+n} x_{j+n}) = 0$$

.....

$$m_{j+n} \frac{d^2 x_{j+n}}{dt^2} - k_j r_{j+n} (r_j x_j - r_{j+n} x_{j+n}) = 0$$

2.3 Arbitrary Inter Chamber Connection (AICC-CR) System

AICC-CR system has multiple chamber with multiple duct. Each chamber is arbitrarily connected to other chamber through duct. Fig.5a shows typical configuration with one main chamber and three sub-chambers.

AICC-CR system is the most complex structure of MDOF-CR systems. Configuration of AICC-CR is various and it is difficult to obtain equations of motions generally. Maximum number of inter-chamber ducts is ${}_nC_2$ where number of chambers is n.

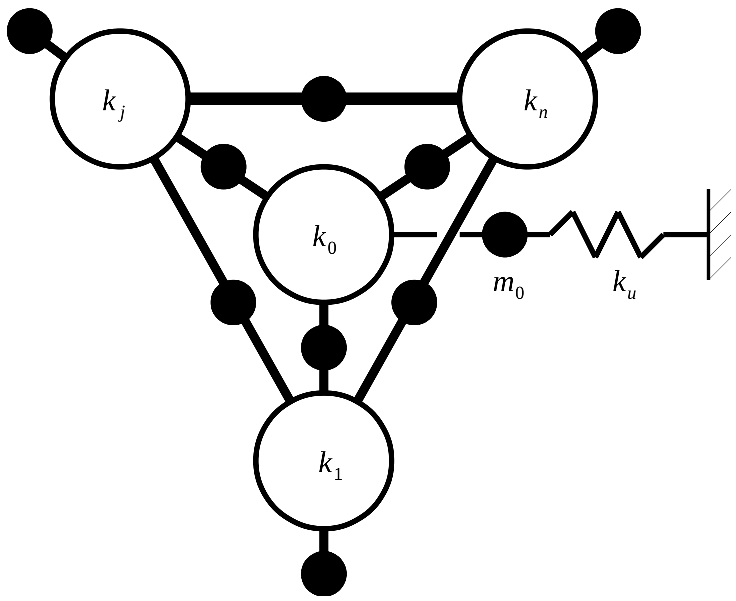

Fig.5a Arbitrary Inter-Chamber Connection Model

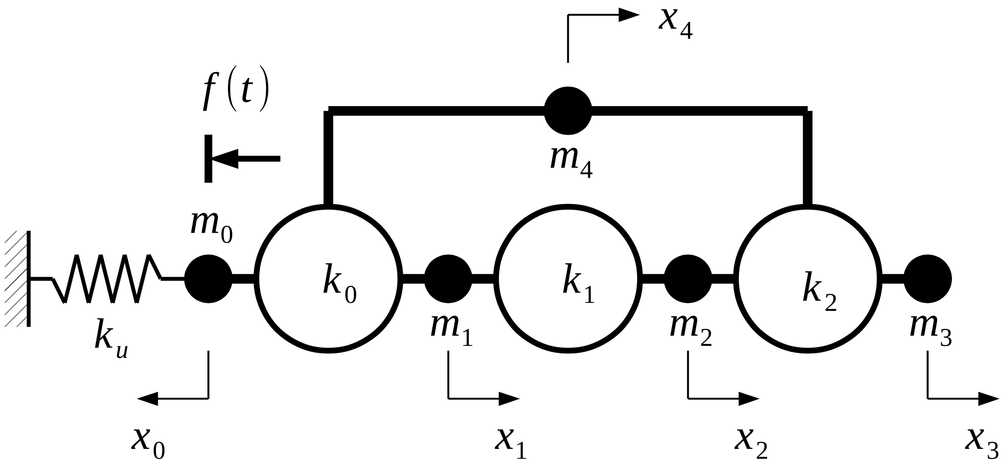

Fig.5b Series Inter-Chamber Connection Model

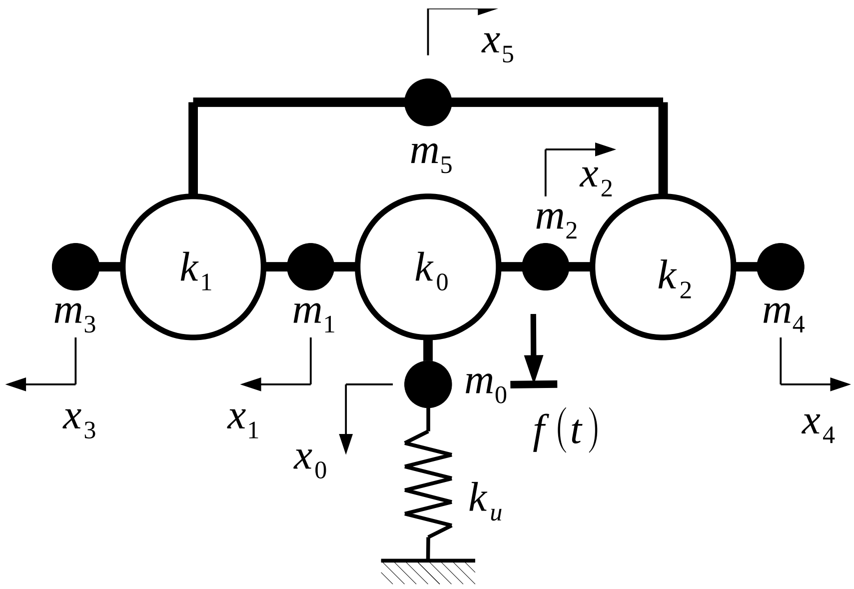

Fig.5c Parallel Inter-Chamber Connection Model

You will find equations of motion of AICC-CR for some typical applications.

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