Study on the LC marker composed of laminated amorphous ribbon core for a wireless magnetic motion capture system

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Abstract. A wireless magnetic motion capture system is one such effective technique for body motion analysis in the field of medical treatment. The applications require a small and thin marker that can be attached to anywhere of a body without breakage. Therefore, thinned LC marker composed of a laminated amorphous ribbon core and a 0.5 mm-thick ferrite plate core were prepared and evaluated. Although, in addition, the ribbons were subjected to field-annealing to control its magnetic anisotropy, there were no differences as the capability of the LC marker. The results reveal that, only near the pick-up coil array (up to 70 mm), the system is capable of detecting the position of the thinned LC marker with the accuracy to around 1 mm.

1. Introduction

Usually, in order to capture a motion of human body, an optical system composed of the optical markers and the video camera are used. The system is effective way for such applications because of the capability of the multi-point detection in real time. When the motion of the functions in the body is required to track, however, the optical system is not always advantageous. Let us consider an example of the case where the marker attached to the function like a tooth may possibly be invisible from the cameras. On the other hand, a magnetic motion capture is useful to detect invisible objects [1-3]. Furthermore, the magnetic field is convenient to use and non-invasive, so that it’s safe for human body. We previously developed a wireless magnetic motion capture system that uses LC resonant magnetic markers (LC markers), which has been considered as a candidate for applications in orthodontics and dentofacial orthopedics [4, 5]. It can not only detect the position of the LC marker as a magnetic dipole, but also the orientation of the LC marker.

In order to obtain an adequate signal-to-noise (S/N) ratio, the LC markers used for evaluating this system were composed of a comparatively large ferrite core and a coil of several hundreds turns. The
applications mentioned above require a small and thin marker that can be attached to a tooth or the tongue. Therefore, we have been investigating several small ferrites and an amorphous ribbon for use as a magnetic core in order to realize downsizing of the LC marker. In a previous study, it found that the amorphous ribbon core composed of a lamination of several ribbon was useful for the core material. In this paper, we study to promote the size reduction of the LC marker using the amorphous ribbons with an acceptable detection accuracy.

2. Experimentals

2.1. Fabrication of the LC markers

A cobalt-based amorphous ribbon (Metaglass 2705M) and a plate-type ferrite (Ni-Zn-type) were used as the magnetic core of the LC markers because these materials have high permeability at relatively high frequency. The given limitation of the marker size advised from a collaborator who is a dentist is less than 5 mm × 5 mm with 1 mm-thick. A polyester enameled copper wire (PEW) was used for the wound coils of all of the markers. Considering the width of the winding coil of 0.1 mm in diameter, those core materials were cut a rectangle shape about 4 mm wide and 5 mm long. At the same time, the thickness of the core must be around less than 0.5 mm. As shown in figure 1, under the size limitation, in order to increase the volume of the core without inducing an eddy current, the amorphous ribbon core (4 mm × 5 mm, thickness: 21 μm) was composed of up to 16 laminations with insulator layers (insulator: 10-μm thick double-sided adhesive tape). Before it’s laminated, in addition, the amorphous ribbons were subjected to a field-annealing in vacuum under several temperature conditions to control a magnetic anisotropy of an easy axis being induced along the cast direction. The relations of the direction among the base ribbon, the cut samples, and the magnetic field are shown in figure 1. The conditions for the field-annealing were as follows; temperature: 473 K (200 °C) to 623 K (350 °C), magnetic field: 240 kA/m (3 kOe). A permeability of the amorphous ribbons was measured using a thin-film permeance meter with shielded loop coil [6]. Figure 2 shows the frequency dependence of the permeability. The real part of permeability of longitudinal direction of the as-cast sample exhibited around 90 at a frequency up to 1MHz. However, the permeability of annealed samples gradually reduced until around 80 as the annealing temperature increases.

|       | As-cast | 473 K | 573 K | 623 K | Ferrite former (20L) |
|-------|---------|-------|-------|-------|---------------------|
| L [μH] | 73.7    | 66.2  | 71.4  | 61.7  | 71.3                |
| C [pF] | 2,300   | 2,590 | 2,350 | 2,350 | 2,350               |
| f₀ [kHz]| 398     | 402   | 399   | 406   | 401                 |
| Q      | 36.8    | 34.8  | 34.9  | 34.3  | 46.5                |

After cutting, the ferrite core was ground until 0.5 mm-thick from 1 mm-thick. The LC markers consist of magnetic cores as well as a wound coil and a chip capacitor, representing an LC series circuit. Table 1 shows the specifications of each LC marker. Excepting the marker using ferrite core,
the resonant frequency of each LC marker was designed so as to provide the highest quality factor of the coils. The specification of the former marker using 20 layers of 2705M (as-cast) was shown in the table too.

2.2. System setup and calculation procedure

A schematic diagram of the developed motion capture system is shown in figure 3. The system is composed of measurement equipment and a coil assembly that consists of an exciting coil and an array of pick-up coils. The pick-up coil array consists of 25 pick-up coils placed at intervals of 45 mm on an acryl board. Each coil consists of 40 turns of PEW wound around an acryl bobbin of 25 mm in diameter. An excitation voltage of 12 Vp-p is applied to the driving coil (13 turns of PEW around a 390 × 390-mm square acryl flame), and the marker is strongly excited at its resonant frequency by electromagnetic induction.

The position and orientation of the markers was obtained by solving an inverse problem, which requires the values of flux density at more than six known locations in order to determine both the position and orientation of the marker as the magnetic flux source (six degrees of freedom) [5]. As shown in figure 3, twenty-five values measured by the pick-up coils were used in the present study. To solve this problem, the flux density generated from the marker is considered as a magnetic dipole field. A localization of those LC markers was verified experimentally as follows. The experiments were carried out to detect the marker when it was placed parallel to the y-axis. The marker was swept from y = 50 mm to 100 mm in 10-mm steps along the y-axis at x = z = 0 mm. (refer figure 3 for the coordinate system). The movement of the marker was done by a precision three-dimensional-axial scanner with positioning accuracy less than 0.1 mm.

A verification results are shown in figure 4. The points in the figures represent 10 measurements at every marker position. The scattering of detected positions gradually spread as the marker left the pick-up coil array, despite of the difference of the marker. This is mainly due to reduction of the S/N ratio. In addition, almost no differences are shown in the figures. Hence, those results were analyzed by both the averaged position and the standard deviation at every marker position as shown in figure 5. From figure 5 (a), we can see the coordinate error of averaged y positions ranging from 3 mm to near 0 mm, which is due to the effect of solid angle of each the pick-up coil and the pick-up coil array as viewed from the marker, so the error percent is minimized around the marker distance equal to half of the side of the array’s area. However, the errors can be compensated by considering the influence of

![Figure 2](image1.png)  
**Figure 2.** Frequency dependence of permeability of the amorphous ribbons.

![Figure 3](image2.png)  
**Figure 3.** Schematic diagram of proposed wireless motion capture system.
the size of both the pick-up coil and the marker [7]. In addition, the S/N ratios are almost same as the former marker regardless of 20 % volume reduction of amorphous core. It is probably due to the difference of the demagnetizing factor.

4. Conclusion
As a result, the system could detect the position of the thinned markers within an accuracy of 1 mm only in the close area from the pick-up coil array (up to 70 mm). There were no differences in the detection results depending on the core material and the annealing effect. However, the amorphous ribbon will be useful as the core material of the LC marker due to unbreakableness, if the further reduction of the marker thickness is required. At any rate, hereafter, it is necessary to improve the S/N ratio of the system to detect the exact location of the small LC markers.

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