Fiber Bragg Grating Sensor Based Device for the Measurement of Hand Grip Strength

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Abstract*— The quantification of human hand grip is important for understanding several important biomechanical aspects like neuromuscular system function, overall upper-limb strength, vertebral fracture and bone mass density (forearm, skeletal sites, spine, hip etc). This paper describes a novel Fiber Bragg Grating sensor based Hand Grip Device (FBGHGD) which can be used to quantify the human hand grip. Here, the strain dependent wavelength responses of FBGs are utilized to obtain the force applied by the human hand grip employing a novel mechanical package. The FBGHGD developed is calibrated using a Compression Testing Machine (CTM) to obtain the relation between the load/force exerted on FBGHGD and the shift in Bragg wavelength of the FBG sensor; this in turn is used to deduce the value of the force exerted in kilograms. Further, the FBGHGD is clinically tested against a commercial Jammer dynamometer with a series of standard test protocols and the obtained results are compared. The demonstrated FBGHGD is accurate and in comparison to dynamometer, it additionally provides real-time variations of the force exerted by hand grip which can be used to deduce several ergonomically vital parameters such as maximum grip force, stamina index, fatigue build-up etc., to aid in better understanding of skeletal muscle function, prediction of disability, incapacity and mortality.

Index Terms*— Fiber Braggs Grating, Hand grip force, Wrist force measurement, Grip force measurement, Musculoskeletal disorder.*

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I. INTRODUCTION

Understanding quantifying the physical strength of a person is necessary for assessing his/her suitability to a specific profession or work [1]. Numerous daily activities require wrist/grip movements and adequate grip force is essential in many workplace environments; hence it is important to measure and understand the different biomechanical aspects of grip strength [2].

In this context, one commonly used measure of physical strength is the Hand Grip Force (HGF) which is known to correlate well with strength of other muscle groups, and display a robust sexual dimorphism [3]. As HGF is a quantity which varies subjectively and changes with respect to several aspects like age, weight, palm size, gender etc., it becomes important and vital to analyse different characteristics of the HGF [1]. It is reported that the measure of HGF has effect in assessing the overall upper-limb strength or even of the whole neuromuscular system function [2], vertebral fracture, and local bone mass at the forearm and also at distant skeletal sites, including the spine and hip [4].

Several observational studies undertaken reveal that among non-athletes, a positive association exists between hand grip force and local bone mass at the wrist or forearm [5]. Thus, it implicitly linked to functional autonomy and hence the quality of life. This relationship had already been well attested in aging people and patients [2].

The measurements of HGF enable therapists and physicians to establish baselines to assess changes/improvement in the patient's ability to generate grip force [6,7]. The HGF assessment is rated as one of the top ten fitness tests and is used as a tool to evaluate an individual's ability to perform physically demanding work tasks [9]. Also, the measurement of HGF is included in many rehabilitation programs to monitor the patients' surgical recovery progress.

In the recent times, there is a significant growth in the application of optical sensor technologies for a wide range of engineering and biomedical applications [6,8]. In particular in the field of biomedical, the fiber optic sensors are not only well exploited for sensing and measuring physiological parameters, but also for measurement of critical chemical and biological parameters [10,11]. The intrinsic electrical isolation and immunity to electromagnetic interference (EMI) of optical fibers are particularly useful in avoiding the risk of electrical shock when used in sensitive hospital environments [12]. Furthermore, the compactness of optical fiber sensors enables localized measurement of organ functions using minimally invasive procedures, providing an accurate information about the required parameters at overall less operating costs [13,14].

Among all other optical sensors, Fiber Bragg Grating (FBG) sensors have proved to be particularly promising due to a number of advantages [15]. FBGs, formed by the modulation of the refractive index of the core of an optical fiber, have been used as excellent sensing element for measuring various physical, chemical and biological parameters, which are of interest in many fields. FBGs are unique in their operation as the sensed parameter is wavelength encoded, making it independent of factors such as fluctuating light levels or power loss, unlike in other types of fiber-optic sensors [16].

In this paper, a Fiber Bragg Grating based Hand Grip measurement Device (FBGHGD) is designed, developed and demonstrated to measure real time hand grip strength which addresses some critical issues in the handgrip measurement leading to clinical implication.

II. DESIGN AND INSTRUMENTATION DETAILS OF FBGHGD

FBGs are known to be highly sensitive and fragile in nature, if not suitably packaged with extreme care; the user may result in damaging the sensor or even scramble the data [17,18]. Hence, a suitable mechanical package is necessary to make the sensor respond selectively to the parameter of interest and also to safeguard the FBG sensor for reuse.

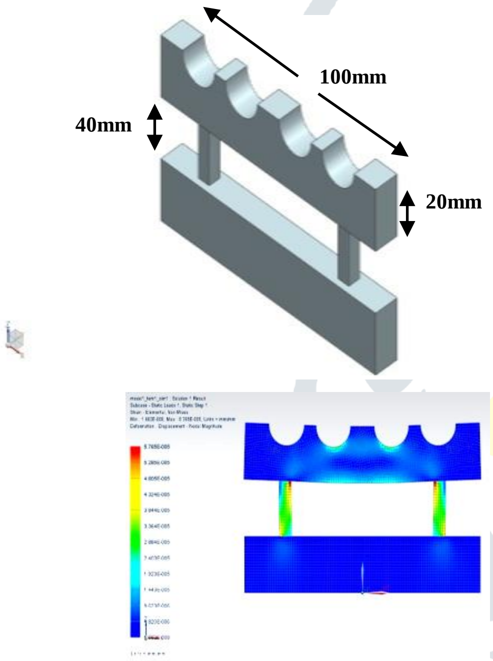


Fig. 1. 3D drawing of the FBGHGD and its strain distribution diagram.

In this work, an ergonomically comfortable mechanical package is designed and developed to suit the measurement of HGF and also to safeguard the FBG sensor.

The FBGHGD developed has two long horizontal bars and two short vertical supports as shown in fig 1. The upper horizontal bar provides four half chamfered grooves to rest fingers for a comfortable grip and the lower horizontal bar is designed for a firm palm grip. The two short vertical legs of the package are positioned symmetrically from the central axis of the package which rests two independent FBG sensors of different Bragg wavelength. The presented design is a product evolved from several modifications and iterations of the initial design with the help of Computer Aided Design and Drawing (CADD) software.

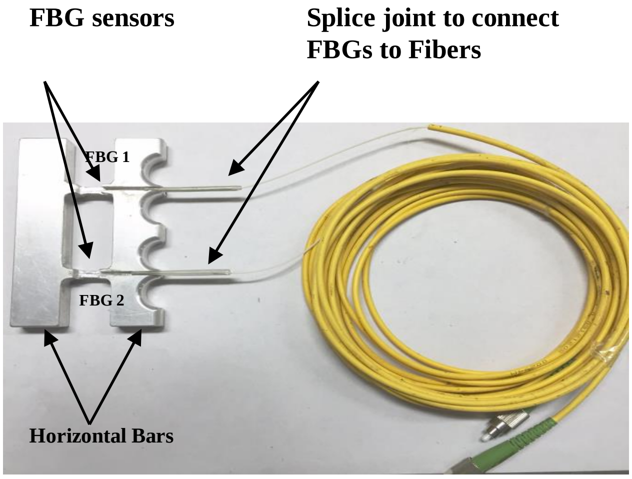


Fig. 2. Pictorial representation of FBGHGD bonded with two FBGs.

Prior to freezing the design of the FBGHGD, material, shape and dimensional aspects are considered for evaluation through several trials with suitable load at the grooves, analyzed using ANSYS structural evaluation software. The computational trials indicate that the use of aluminum 1100 grade, with 100mm horizontal bars and 40mm vertical legs provide a sensible amount of strain on the vertical legs upon exerting a nominal hand grip. These computational studies have also identified the maximum strain locations on the vertical legs which are further used to bond FBG sensors. This exercise of locating hot spots from strain analysis of the FBGHGD has assisted in the bonding of the FBG sensors to attract maximum strain which will lead to a better signal to noise ratio.

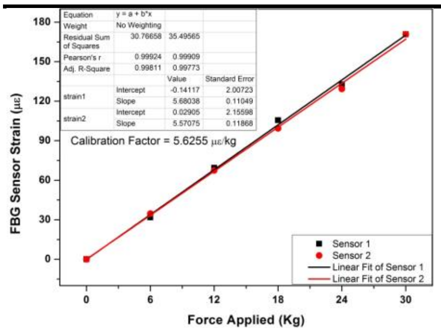
Fig 2 shows the pictorial representation of FBGHGD, where two FBG sensors (FBG1=1551nm and FBG2=1523nm) are bonded on two independent vertical supports. These two FBG sensors are further connected to two independent channels of a FBG interrogator (SM 130-700, Micron Optics Inc.) which can record the change in Bragg wavelength of the FBGs due to applied hand grip load.

III. CALIBRATION OF FBGHGD

Before the onset of clinical trials, the required calibration procedure is followed to obtain the relation between the load applied on FBGHGD and the respective change in Bragg wavelength of FBGs.

Vertical Supports

Splice Joint to connect FBGs to Fibers



(a) (b)

Fig. 3. Calibration setup and plot of developed FBGHGD.

During the calibration phase, the FBGHGD is subjected to a force using a manually loaded Compression Testing Machine (CTM). The CTM is made to exert controlled force on the upper surface of the horizontal bar by using a screw type mechanism. Since the force exerted on the FBGHGD is from top to bottom, the FBGs bonded on the vertical support undergo compression reading a negative shift in wavelength which is considered positive for the purpose of illustration. The change in Bragg wavelength of FBGs from the FBGHGD and load exerted by CTM are simultaneously acquired and stored in the calibration dataset. The recorded wavelength shift from the FBGHGD is converted to respective strain (με) using the standard conversion factor of 1.22pm/με [19]. Fig 3 shows the pictorial representation of the calibration setup depicting the CTM and the FBGHGD under test along with the calibration plot in which the strain generated in FBG1 and FBG2 are plotted against applied load applied in the CTM. A linear fit of the points of the plot provide the necessary calibration factor (5.6255 με/kg). From the plot, it can be noted that the responses of both FBG sensors are similar and follow a common trend and hence a common calibration factor can be accepted for both FBG1 and FBG 2.

IV. EXPERIMENTAL PROTOCOL

Experiments have been carried out using the FBGHGD developed and the commercial Jammer hydraulic hand dynamometer for a common experimental protocol. Fig 4 shows the actual photographs of both FBGHGD and Jammer hydraulic hand dynamometer.

Fig. 4. The Photograph of both FBGHGD and Jammer hydraulic hand dynamometer.

V. EXPERIMENTAL DETAILS

A. Participants

10 Healthy subjects, free from any musculoskeletal or neurological disorders, volunteered for this study. The subjects with comparable palm size to suit the developed FBGHGD have been chosen. These subjects are advised not to consume alcohol or any sort of medication, 24 h prior to the commencement of the experiment. The subjects are also instructed about the experiment and each subject is given a trial run before the readings are taken. The required clearance from the human ethical committee of the institution has been obtained for undertaking these studies.

B. Methodology

The experiment is conducted in a clinical environment under the guidance of a physician. The volunteered subjects are advised to sit comfortably on a chair and rest their hand on a position that is least apprehensive. Fig 5 shows the pictorial representation of a subject with FBGHGD and Jammer hydraulic hand dynamometer during the experiment. As mentioned earlier, the medically well accepted Jammer hydraulic hand dynamometer is used here for the purpose of validating the developed FBGHGD [20,21]. The dynamometer, which is a hydraulic device used to determine grip strength by measuring mechanical forces or torques using the elastic deformation produced, is an important constituent of the handgrip-testing methodology [22].

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Fig. 5. Photograph of a subject using both FBGHGD and Jammer hydraulic hand dynamometer.

The experiment spans for a duration of about 30 seconds which is divided into three equal parts of 10 seconds. For the first 10 seconds, the subject is expected to adjust to FBGHGD to a more comfortable position within the palm. For the next 10 seconds, the subject is expected to apply his/her maximum possible grip force by trying to compress the FBGHGD. The last 10 seconds of the experimental time is used to release the FBGHGD from the applied hand grip force. The subjects are instructed to repeat this cycle for three times with sufficient time gap to avoid fatigue effect in to the recorded grip forces.

In order to facilitate post-processing of the data, FBG interrogator has been configured to acquire data at a sampling rate of 1kHz. Since the Jammer hydraulic hand dynamometer used in the present study is of manual type, the intermediate 10 seconds during which the subject exerts the maximum grip force (kg) is manually recorded. To compare the obtained results of FBGHGD, the change Bragg wavelength due to exerted hand grip force is first converted to respective strain and then further converted to comparable force (kg) though the calibration factor obtained from the calibration trials of FBGHGD.

VI. RESULT AND DISCUSSIONS

Three distinct aspects of the experiments are conducted in the present study. Firstly, the response of FBGs for the applied hand grip force by a representative subject is illustrated through real-time strain variation. Secondly, a quantitative comparison of FBGHGD against the dynamometer is carried out to observe the match in magnitude of their responses. Finally, the quantitative analysis of FBGHGD for evaluating its performance through line plot analysis is carried out.

The grip force of the subject on the FBGHGD generates a relative strain on the surface bonded FBG sensors which can be recorded in real-time using the FBG interrogator. For the purpose of illustration, the response of one of the FBG sensors of FBGHGD for left and right hand grip is shown in Fig 6. This figure shows the real-time response of FBG sensors for the interim 10 seconds duration of the 30 seconds experimental time where the subject is advised to exert maximum force on FBGHGD. The illustration plot represents the response of one of the FBG sensors of FBGHGD. However the similar tends has been observed to the other FBG sensor as well.

From Fig 6, it can be noted that the maximum magnitude of strain generated by right hand grip force of the subject is about 95με (16.96 kg) whereas for left hand it is about 41με (7.32 kg). The converted force value of right hand grip force exceeds left hand grip force by about 2.3 times which is sensible as the subject under test is a right hander. However, this difference in force applied by right and left hand is subjective and varies by individual`s BMI, age, gender etc. Apart from finding the magnitude of forces, it can also be seen from the shape of the curves that the right hand force curve is more graceful (flat top) compared to the left hand force curve (sharp top) which signifies the stamina of the subject to hold the maximum force for longer time. For the purpose of illustration, the magnitude of the FBG sensors has been reversed. However in practice the FBG sensors of FBGHGD undergo compression. This method of analysis can be significant to clinically diagnose several diseases connected to musculoskeletal disorders[23,24].

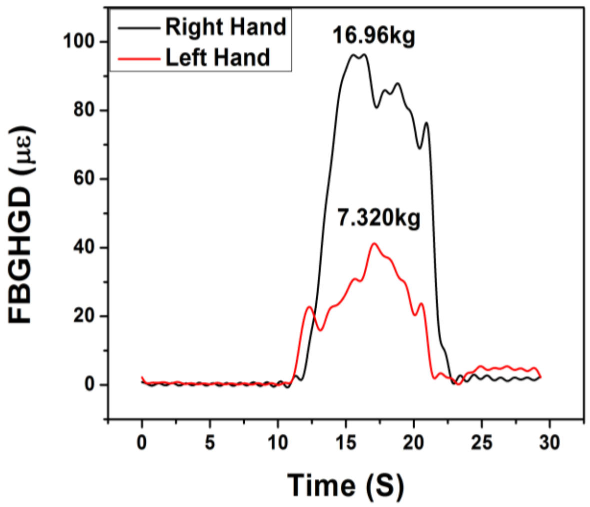

Fig. 6. Real-time response of one of the FBG sensors of FBGHGD for left and right hand.

Fig 7 shows the evaluation plot where the response of FBGHGD (average of FBG1 and FBG2) and dynamometer are analyzed for the entire set of volunteered subjects. The data set for this plot from FBGHGD is generated from the averaged values of all the three trials of each subject. The X-axis shows the subjects under test and the two Y-axis shows the force generated in FBGHGD and dynamometer. From the plot, it is evident that the response of FBGHGD is matching with the response of the dynamometer for the volunteered subject, indicating the reliability and accuracy of the measurement results obtained from FBGHGD. This plot can also offer to list the subjects under test, on the basis of their handgrip force which can be an indicator for assessing suitability of the subjects for certain professions like sports and other works involving handgrip force [25,26] .

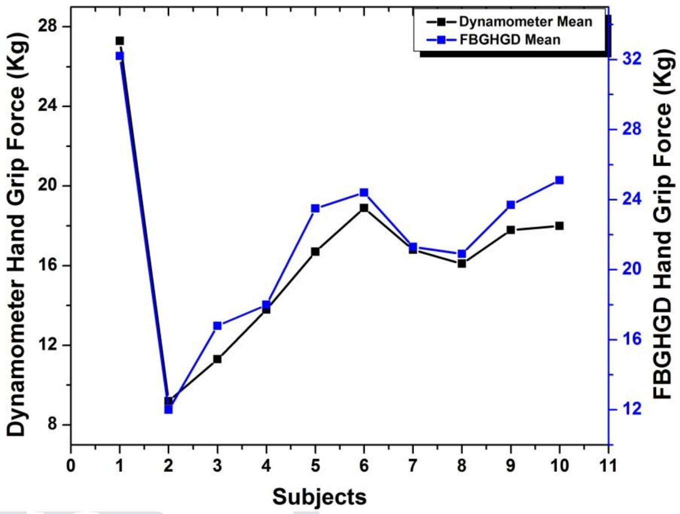

Fig. 7. Response of both FBGHGD and Jammer hydraulic hand dynamometer for right hand of ten subjects.

VII. CONCLUSION

A novel Fiber Bragg Grating Sensor based Hand Grip Device (FBGHGD) has been designed, developed and demonstrated to measure the real-time grip strength. The strain dependent wavelength response of FBGs is utilized to obtain the amount of force being applied by the hand grip. The temporal response of the FBGHGD has also been studied under suitable protocols and results obtained. Further, the FBGHGD is clinically tested against a commercial Jammer dynamometer with a series of standard test protocols and the obtained results are compared. The demonstrated FBGHGD is accurate and in comparison to dynamometer, it additionally provides real-time variations of the force exerted by hand grip which can be used to deduce several ergonomically vital parameters such as maximum grip force, stamina index, fatigue build-up etc., to aid in better understanding of skeletal muscle function, prediction of disability, incapacity and mortality.

As the FBG sensor is small in size, free from electromagnetic interference and needs no energizing current to activate the sensor, the demonstrated device can be useful in biomechanical, biomedical applications. Further, the FBGHGD developed also has a low risk of infection, high accuracy and well correlated features like real time variations, which give it an edge over the existing devices such as the dynamometer. The FBGHGD developed has a great potential in the field of sports involving human trials, especially in rehabilitation programs.

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