

LASER SURFACE TEXTURING OF FREEFORM  
SURFACES OF ARTICULATING COMPONENTS  
FOR ENHANCED TRIBO-CORROSION  
PROPERTIES

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CENTRE FOR BIOMEDICAL ENGINEERING  
INDIAN INSTITUTE OF TECHNOLOGY DELHI  
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ENHANCED TRIBO-CORROSION PROPERTIES

*by*

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## Certificate

This is to certify that the thesis entitled “Laser Surface Texturing of Freeform Surfaces of Articulating Components for Enhanced Tribo-Corrosion Properties” being submitted by Mr. K.E.Ch.Vidyasagar to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy is a record of original research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my best knowledge has reached the requisite standard.

The results contained in this thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.



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# ABSTRACT

Artificial Implants surgeries increased rapidly due to changes in lifestyle and technological advancements. The long-term in-vitro use of the implants has resulted in failure in a significant number of cases, thereby demanding revision surgeries. Among the several causes of failure, release of metal ions, fretting corrosion, pitting and crevice corrosion etc., induced and amplified fatigue due to loading were most common. Surface modification techniques, including heat treatment, coatings with diamond-like carbon or coatings with other materials, ball burnishing, and laser surface texturing, are some of the common methods employed by industries to deal with tribo-corrosion issues. Among these, Laser surface texturing is proven to be one of the best surface modification techniques for the improvement of tribo-corrosion properties. Pulsed laser-based micro-texturing induces topographical and chemical modifications on surfaces that yield beneficial properties such as anti-microbial effect, microhydrodynamic bearing, and surface hardening. These properties find a multitude of applications in surface treatment and tribology. However, laser texturing of free-form surfaces is a cost and effort-intensive process, specifically for medical implants or ergonomically designed tools/devices. Such components often require numerically controlled 3 or 5 axes machines and sophisticated computer-aided manufacturing (CAM) software for precise tool movement. The presented thesis is focused on designing, fabricating, and validating a jerkfree, cost-effective Stewart platform that works in tandem with an existing laser machining setup for texturing of freeform surfaces. A microcontroller and stepper motor-based linear actuators were used to orient and translate the six-degrees-of-freedom (DoF) platform. A customized computer program helped manoeuvre the workpieces (medical implants) for the micro texturing of the 3D surface profiles. As laser irradiation demands a time-invariant focal length for effective ablation, the platform maintains the focal length from the galvo-scanner of the

laser machine to the workpiece while manoeuvring the workpiece throughout the texture trajectory. The trajectories for the platform to enable texturing of the surfaces of implants were generated through the implant's CAD models. Using inverse kinematics, the platform leg lengths required to maneuver the points on the surfaces of implants to the laser focal point were computed. The implants were maneuvered through the platform accurately under the laser machine, and their freeform surfaces were textured. The platform has the following linear traverse and rotational limits: x travel: 45 mm; y travel: 45 mm; z travel: 50 mm; tilt about x axis:  $\pm 25^\circ$ ; tilt about y axis:  $\pm 25^\circ$  and tilt about z axis:  $\pm 60^\circ$ . Thereafter free form surfaces like knee implants (femoral component), dental wire, and hip implants (femoral head) was textured with the help of the Stewart platform. Texturing has been successfully performed on implant freeform surfaces with an average diameter of  $\sim 35$  to  $40 \mu\text{m}$  and depth of  $\sim 15$  to  $20 \mu\text{m}$ . Thereafter the corrosion and tribological analysis of laser-textured freeform surface components was performed. An increase in tribological performance and corrosion resistance was observed in the case of laser-textured freeform surfaced components when compared with untextured freeform surfaced components.

## सार

जीवनशैली में बदलाव और तकनीकी प्रगति के कारण कृत्रिम प्रत्यारोपण सर्जरी में तेजी से वृद्धि हुई है। प्रत्यारोपण के लंबे समय तक इन-विट्रो उपयोग के परिणामस्वरूप महत्वपूर्ण संख्या में मामले विफल हो गए हैं, जिससे संशोधन सर्जरी की आवश्यकता है। विफलता के कई कारणों में, धातु आयनों की रिहाई, झल्लाहट जंग, गड्ढे और दरार जंग आदि, लोडिंग के कारण प्रेरित और प्रवर्धित थकान सबसे आम थी। ट्राइबो-जंग के मुद्दों से निपटने के लिए उद्योगों द्वारा नियोजित कुछ सामान्य तरीकों में गर्मी उपचार, हीरे की तरह कार्बन के साथ कोटिंग्स या अन्य सामग्रियों के साथ कोटिंग्स, बॉल बर्निंग और लेजर सतह बनावट शामिल हैं। इनमें से लेजर सरफेस टेक्सचरिंग ट्राइबो-करोशन गुणों के सुधार के लिए सबसे अच्छी सरफेस मॉडिफिकेशन तकनीकों में से एक साबित हुई है। स्पंदित लेजर-आधारित माइक्रो-टेक्सचरिंग सतहों पर स्थलाकृतिक और रासायनिक संशोधनों को प्रेरित करता है जो लाभकारी गुणों जैसे कि एंटी-माइक्रोबियल प्रभाव, माइक्रोहाइड्रोडायनामिक असर और सतह को सख्त बनाता है। इन गुणों को सतह के उपचार और ट्राइबोलॉजी में बहुत सारे अनुप्रयोग मिलते हैं। हालांकि, फ्री-फॉर्म सतहों का लेजर टेक्सचरिंग एक लागत और प्रयास-गहन प्रक्रिया है, विशेष रूप से चिकित्सा प्रत्यारोपण या एर्गोनॉमिक रूप से डिज़ाइन किए गए टूल/डिवाइस के लिए। इस तरह के घटकों को सटीक उपकरण आंदोलन के लिए संख्यात्मक रूप से नियंत्रित 3 या 5 अक्ष मशीनों और परिष्कृत कंप्यूटर-एडेड मैनुफैक्चरिंग (सीएएम) सॉफ्टवेयर की आवश्यकता होती है। प्रस्तुत थीसिस एक जर्कफ्री, लागत प्रभावी स्टीवर्ट प्लेटफॉर्म को डिजाइन करने, बनाने और मान्य करने पर केंद्रित है जो फ्रीफॉर्म सतहों की बनावट के लिए मौजूदा लेजर मशीनिंग सेटअप के साथ मिलकर काम करता है। एक माइक्रोकंट्रोलर और स्टेपर मोटर-आधारित लीनियर एक्ज्युटर्स का उपयोग सिक्स-डिग्री-ऑफ-फ्रीडम (डीओएफ) प्लेटफॉर्म को उन्मुख और अनुवाद करने के लिए किया गया था। एक अनुकूलित कंप्यूटर प्रोग्राम ने 3डी सतह प्रोफाइल के सूक्ष्म बनावट के लिए वर्कपीस (चिकित्सा प्रत्यारोपण) को चलाने में मदद की। जैसा कि लेजर विकिरण प्रभावी पृथक्करण के लिए समय-अपरिवर्तनीय फोकल लम्बाई की मांग करता है, प्लेटफॉर्म लेजर मशीन के गैल्वो-स्कैनर से वर्कपीस तक फोकल लम्बाई को बनाए रखता है जबकि वर्कपीस को बनावट प्रक्षेपवक्र में घुमाता है। इम्प्लांट के सीएडी मॉडल के माध्यम से इम्प्लांट की सतहों की बनावट को सक्षम करने के लिए प्लेटफॉर्म के लिए प्रक्षेपवक्र उत्पन्न किए गए थे। व्युत्क्रम कीनेमेटिक्स का उपयोग करते हुए, लेजर फोकल बिंदु पर प्रत्यारोपण की सतहों पर बिंदुओं को घुमाने के लिए आवश्यक प्लेटफॉर्म पैर की लंबाई की गणना की गई। इम्प्लांट्स को प्लेटफॉर्म के माध्यम से लेजर मशीन के तहत सटीक रूप से संचालित किया गया था, और उनकी फ्रीफॉर्म सतहों को टेक्सचर किया गया था। प्लेटफॉर्म में निम्नलिखित रैखिक ट्रेवर्स और घूर्णी सीमाएँ हैं: x यात्रा:

45 मिमी; वाई यात्रा: 45 मिमी; जेड यात्रा: 50 मिमी; एक्स अक्ष के बारे में झुकाव:  $\pm 25^\circ$ ; वाई अक्ष के बारे में झुकाव:  $\pm 25^\circ$  और जेड अक्ष के बारे में झुकाव:  $\pm 60^\circ$ । उसके बाद स्टीवर्ट प्लेटफॉर्म की मदद से घुटने के प्रत्यारोपण (फेमोरल कंपोनेंट), डेंटल वायर और हिप इम्प्लांट्स (फेमोरल हेड) जैसी सतहों से मुक्त किया गया।  $\sim 35$  से  $40$  माइक्रोन के औसत व्यास और  $\sim 15$  से  $20$  माइक्रोन की गहराई के साथ इम्प्लांट फ्रीफॉर्म सतहों पर टेक्सचरिंग सफलतापूर्वक किया गया है। तत्पश्चात लेज़र-बनावट मुक्त सतह घटकों के क्षरण और ट्राइबोलॉजिकल विश्लेषण का प्रदर्शन किया गया। लेज़र-बनावट वाले फ्रीफॉर्म सतह वाले घटकों के मामले में ट्राइबोलॉजिकल प्रदर्शन और संक्षारण प्रतिरोध में वृद्धि देखी गई जब इसकी तुलना बिना बनावट वाले फ्रीफॉर्म सतह वाले घटकों से की गई

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