Opis raziskovalnega dela *(Research work description*)

1. Članica UL (*UL member)*:

Fakulteta za elektrotehniko

2. Ime, priimek in elektronski naslov mentorja/ice (*Mentor's name, surname and email*):

Tomaž Gyergyek tomaz.gyergyek@fe.uni-lj.si

3. Raziskovalno področje (*Research field*):

Fizika

4. Opis raziskovalnega dela *(Research work description*):
Vključuje morebitne dodatne pogoje, ki jih mora izpolnjevati kandidat/ka za mladega raziskovalca/ko, ki niso navedeni v razpisu za mlade raziskovalce *(It includes any additional conditions that the candidate for a young researcher must meet, which are not listed in the call to tender for young researchers.)*.

Slov.: # Tema doktorske disertacije: Fizikalno utemeljeno načrtovanje komponent v stiku s plazmo za fuzijske reaktorje

V tokamaku so komponente v stiku s plazmo (PFC) v divertorju izpostavljene največjim toplotnim in delčnim tokovom v napravi. V napravah ITER, WEST, JT-60SA in DTT gre za volframove monobloke, nameščene na vodno hlajeno cev iz zlitine CuCrZr, ki so v stacionarnem obratovanju izpostavljeni okoli 10 MW/m², ob prehodnih dogodkih pa tudi nad 20 MW/m². Bloki so oblikovani tako, da so njihovi vodilni robovi magnetno senčeni s strani sosednjih elementov, vendar je novejše delo skupine CEA/IRFM pokazalo, da ta zaščita ni popolna: med robno lokaliziranimi načini (ELM) imajo vpadni ioni energije več keV in ciklotronske polmere nekaj milimetrov, zato jih del s kroženjem obide senčenje in zadene domnevno zaščitene vodilne robove, kar vodi v taljenje in rekristalizacijo volframa. CEA/IRFM je zato predlagal komponento povsem brez ostrih robov — volframove stožce, nanizane na hlajeno cev, navdihnjene z obliko provansalskih korcev — ki bi poleg tega dopuščala milimetrska odstopanja pri sestavi namesto tolerance ±0,3 mm, zahtevane v napravi ITER, kar bi bistveno zmanjšalo stroške in zapletenost izdelave divertorja.

Ta zasnova je bila doslej ovrednotena le dvodimenzionalno in zgolj s fizikalnega vidika. Predmet doktorata je odgovoriti, izhajajoč iz prvih načel, kakšna naj dejansko bo oblika divertorske komponente. Kandidat bo razvil in uporabil verigo simulacij, ki sega od kinetičnega opisa plazme na površini prek prostorsko razrešenega toplotnega toka na povsem tridimenzionalni geometriji do toplotnega in mehanskega odziva hlajene komponente, ter z njo pretehtal možne zasnove glede na najvišjo sprejemljivo temperaturo, varnostni faktor do rekristalizacije, sile ob motnjah, enostavnost izdelave in dopustna odstopanja pri sestavi. Geometrija s stožčastimi korci je izhodišče študije, ne njen sklep: če analiza pokaže, da je boljša drugačna oblika — izboljšan klasičen blok, spremenjen korec ali geometrija, ki jo predlaga kandidat sam — bomo sledili tej rešitvi. Prav ugotovitev, katera geometrija je zares najboljša, je raziskovalno vprašanje.

Skupina ima potrebna orodja na voljo, kandidat pa jih lahko po lastni presoji izbira, nadgrajuje ali dopolnjuje z drugimi. Izračune toplotnih tokov z upoštevanjem ciklotronskega gibanja ionov na poljubnih CAD geometrijah opravljamo s kodo GYROHIT, določanje s plazmo omočenih površin in profilov vzporednega toka s kodo RipTrace, ki je nastala v našem laboratoriju, toplotno-mehanski odziv pa z delovnim tokom, zasnovanim na programju OpenFOAM; porazdelitve hitrosti, ki vstopajo v izračun, izhajajo iz kinetičnih simulacij plašča pred divertorjem po metodi delcev v celici (PIC). Prehod od idealizirane dvodimenzionalne geometrije k realističnim tridimenzionalnim komponentam je sam po sebi zahteven algoritmičen problem. Delo je računsko zahtevno in bo potekalo na evropski superračunalniški infrastrukturi, zato bo kandidat pridobil tudi konkretne izkušnje z vzporednim računanjem in računanjem na grafičnih procesorjih. Napovedi bomo soočili z namenskimi poskusi na tokamaku WEST, uporabljena metodologija pa je neposredno prenosljiva na naprave JT-60SA, DTT, ITER in DEMO.

Mentor bo prof. dr. Tomaž Gyergyek s Fakultete za elektrotehniko Univerze v Ljubljani. Somentor bo dr. James P. Gunn z Institut de recherches sur la fusion magnétique (IRFM), CEA Cadarache — vrhunski strokovnjak za interakcijo plazme s steno, odgovoren za sisteme Langmuirjevih sond na tokamaku WEST, nosilec treh pogodb Organizacije ITER s področja načrtovanja in ocenjevanja divertorja ter avtor obravnavane zasnove komponente. Kandidat bo tesno sodeloval z laboratorijem LeCAD na Fakulteti za strojništvo Univerze v Ljubljani — z dr. Jernejem Kovačičem, dr. Maticem Brankom in izr. prof. dr. Leonom Kosom — in bo v neprekinjenem stiku s CEA; med doktorskim študijem je predvidenih več delovnih obiskov v Cadarachu.

Zaželeno je, da ima kandidat nekaj predznanja s področja fizike plazme in numeričnih metod ter izkušnje s programiranjem, po možnosti v jeziku C++ ali Python. Posebej dragoceno je dobro matematično znanje, saj so izračuni ionskih orbit in magnetnih silnic izrazito geometrijske in algoritmične narave. Poznavanje delovnega okolja

Linux/HPC ter orodij za CAD in mreženje je prednost, ni pa nujno, saj ga je mogoče pridobiti med doktorskim študijem. Nujno je dobro znanje angleščine, saj delo poteka v mednarodni skupini. Od kandidata pričakujemo, da bo rezultate objavljal v revijah prvega in drugega kvartila s področja fuzije in fizike plazme, jih predstavljal na mednarodnih konferencah ter se vpisal v doktorski študijski program Jedrska tehnika Univerze v Ljubljani.

Doctoral research topic: Physics-based design of plasma-facing components for fusion reactors

In a tokamak, the plasma-facing components (PFCs) of the divertor receive the highest heat and particle fluxes in the machine. In ITER, WEST, JT-60SA and DTT they are tungsten monoblocks assembled along a water-cooled CuCrZr tube, exposed to some 10 MW/m² in steady state and to transients above 20 MW/m². The blocks are shaped so that their leading edges are magnetically shadowed by their neighbours, but recent work at CEA/IRFM has shown that this protection is incomplete: during edge-localised modes the impacting ions carry energies of several keV and have Larmor radii of a few millimetres, so a fraction of them gyrate around the shadowing geometry and strike the supposedly protected edges, causing melting and recrystallisation of the tungsten. CEA/IRFM has therefore proposed a component with no sharp edges at all — conical tungsten beads threaded on a cooled tube, inspired by Provençal roofs covered with Roman tiles — which would in addition tolerate assembly misalignments of millimetres rather than the ±0.3 mm demanded in ITER, substantially reducing the cost and complexity of divertor manufacturing.

That concept has so far been assessed only in a two-dimensional, physics-only study. The subject of this doctorate is to answer, from first principles, what a divertor component should actually look like. The candidate will develop and apply a simulation chain that runs from the kinetic description of the plasma at the surface, through the resolved heat flux on a fully three-dimensional geometry, to the thermal and mechanical response of the cooled component, and will use it to weigh candidate designs against peak temperature, recrystallisation margin, disruption forces, manufacturability and assembly tolerance. The bead geometry is the starting point of the study, not its conclusion: should the analysis show that a different shape — an improved conventional block, a modified bead, or a geometry the candidate proposes — performs better, that solution will be pursued instead. Establishing which geometry is genuinely the best is the research question.

The group has the necessary tools in place, and the candidate is free to choose among them, extend them, or bring others. Gyro-orbit-resolved heat-flux calculations on arbitrary CAD geometries are performed with GYROHIT, plasma-wetted areas and parallel flux profiles with RipTrace, our in-house field-line tracing code, and the thermomechanical response with an OpenFOAM multi-region workflow; the velocity distributions entering the calculation come from kinetic particle-in-cell simulations of the divertor sheath. Taking these from idealised two-dimensional geometry to realistic three-dimensional components is a substantial algorithmic problem in its own right. The work is computationally demanding and will be carried out on European high-performance computing infrastructure, so the candidate will also gain solid experience in parallel and GPU computing. The predictions will be validated against dedicated experiments on the WEST tokamak, and the methodology is directly transferable to JT-60SA, DTT, ITER and DEMO.

The supervisor will be Prof. Dr Tomaž Gyergyek of the Faculty of Electrical Engineering, University of Ljubljana. The co-supervisor will be Dr James P. Gunn of the Institut de recherches sur la fusion magnétique (IRFM), CEA Cadarache — a senior expert in plasma–wall interaction, responsible for the Langmuir probe systems of the WEST tokamak, holder of three ITER Organization contracts on divertor design and assessment, and the originator of the component concept examined here. The candidate will collaborate closely with the LeCAD laboratory of the Faculty of Mechanical Engineering, University of Ljubljana — with Dr Jernej Kovačič, Dr Matic Brank and Assoc. Prof. Dr Leon Kos — and will be in continuous contact with CEA; several working visits to Cadarache are foreseen during the doctorate.

It is desirable that the candidate has some prior knowledge of plasma physics and numerical methods, together with programming experience, preferably in C++ or Python. A solid mathematical background is particularly valuable, since the orbit and field-line calculations are strongly geometrical and algorithmic in character. Familiarity with a Linux/HPC working environment and with CAD and meshing tools is an advantage but can be acquired during the doctorate. A good command of English is required, as the work is carried out within an international collaboration. The candidate is expected to publish the results in first- and second-quartile journals in the field of fusion and plasma physics, to present them at international conferences, and to enrol in the doctoral study programme in Nuclear Engineering at the University of Ljubljana.

5. Priloge, ki jih je treba priložiti ob prijavi *(Documents required to be submitted with the application)*:

☒ **potrdilo o doseženi izobrazbi *(proof of completed education)***

- kandidat z zaključenim magistrskim študijskim programom (2. bolonjska stopnja)
  (candidate who has completed a Master's degree (2nd Bologna level)):
  - diplomska listina / potrdilo o zaključku študijskega programa
    (diploma certificate / certificate of completion of the study programme)
  - priloga k diplomi / potrdilo o opravljenih obveznostih
    (diploma supplement / official transcript of records containing all grades obtained in the study programme)

- kandidat, ki še ni zaključil študija na 2. stopnji
  (candidate who has not yet completed a Master's degree):

  - potrdilo o do sedaj opravljenih obveznostih z ocenami magistrskega študijskega programa, s katerim se bo kandidat prijavil na doktorski študij
    (official transcript of records listing all courses and grades obtained so far in the Master's degree programme on the basis of which the candidate will apply for enrollment in a doctoral degree programme.)

☐ **nagrade –** univerzitetna Prešernova nagrada ali Prešernova nagrada članice Univerze v Ljubljani oz. druga enakovredna nagrada *(awards, e.g. Prešeren Prize of the University of Ljubljana, Prešeren Prize of a University of Ljubljana member and/or another equivalent award))*

☐ **bibliografija** *(bibliography)*

☒ **življenjepis** *(CV)*

☐ **motivacijsko pismo** *(motivation letter)*

☐ **opis dosedanjega sodelovanja pri raziskovalnem delu** *(description of the candidate's research work)*

☐ **osnutek idejne zasnove raziskovalnega dela** *(preliminary research proposal)*

☐ **priporočilno pismo** *(letter of recommendation)*

☐ **druge priloge** *(other attachments):*

Opis raziskovalnega dela *(Research work description*)

1. Članica UL (*UL member)*:

Univerza v Ljubljani, Fakulteta za elektrotehniko *University of Ljubljana, Faculty of Electrical Engineering*

2. Ime, priimek in elektronski naslov mentorja/ice (*Mentor's name, surname and email*):

Matej Možek (matej.mozek@fe.uni-lj.si) *Matej Možek (matej.mozek@fe.uni-lj.si)*

3. Raziskovalno področje (*Research field*):

2.09 Elektronske komponente in tehnologije *2.09 Electronic components and technologies*

4. Opis raziskovalnega dela *(Research work description*):
Vključuje morebitne dodatne pogoje, ki jih mora izpolnjevati kandidat/ka za mladega raziskovalca/ko, ki niso navedeni v razpisu za mlade raziskovalce *(It includes any additional conditions that the candidate for a young researcher must meet, which are not listed in the call to tender for young researchers.)*.

Slov.: Tema raziskovalnega dela mladega raziskovalca/ke (MR) bo načrtovanje, izdelava in integracija MEMS senzorskih in aktuatorskih struktur nadgrajenih s pametno elektroniko, kar bo vodilo v realizacijo kompleksnejših mikroelektronskih sistemov za avtomatizacijo, pametne naprave in industrijske procese. Delo MR predstavlja nadaljevanje obstoječih raziskav Laboratorija za mikrosenzorske strukture in elektroniko (LMSE) na področju polprevodniške tehnologije, MEMS, elektronskih vezij, mikrofluidike in debelo- ter tankoplastnih materialov v elektroniki. Cilj raziskovalnega dela MR je nadgraditev obstoječih znanj s sistemi, ki bodo poleg osnovnih mikrofluidnih funkcij (kontrole pretoka, mešanja, usmerjanja itd.) izvajali še druge pomembne funkcije, kot so merjenje temperature, prevodnosti (slanost vode), globine, biološko zaznavanje, zbiranje električnega naboja idr. Narava dela MR bo izrazito interdisciplinarna, saj bo vključevala raziskovalna področja materialov, mikrofluidike, elektronskih komponent, vezij, numeričnih simulacij in programiranja. Tema MR se tesno prepleta z izvajanjem obstoječih projektov programske skupine Mikrostrukture in nanostrukture in ostalih projektov, ki jih izvaja raziskovalna skupina LMSE. MR mora imeti sposobnost strokovnega delovanja v mednarodnem okolju, kar zajema osnove pisanja znanstvenih člankov in dobro znanje angleškega jezika (B2/C1). Od MR se pričakuje visoka motiviranost, ki obsega samoiniciativnost, inovativnost, natančnost in zanesljivost pri delu. MR se aktivno vključuje v ekipo LMSE, pri čemer mora pokazati vnemo za sodelovanje z ostalimi sodelavci LMSE. MR bo opravljal/a doktorski študij na doktorskem študijskem programu Elektrotehnika, Univerze v Ljubljani.

Eng.:
Main research topic of the young researcher candidate (YRC) will be the design, manufacturing and integration of silicon sensor and actuator structures with smart electronics, which will lead to the realization of more complex microelectronic systems for medical, pharmaceutical or chemical process engineering applications.

Research work of YRC will represent a continuation of existing research of the Laboratory for Microsensor Structures and Electronics (LMSE) in the field of semiconductor technology, MEMS, electronic circuits, microfluidics and thick- and thin-film materials in electronics.

Primary aim of YRC research work is to expand existing knowledge in the field of advanced sensor systems for key applications in medicine, pharmacy and chemical process engineering. In addition to basic microfluidic functions (flow control, mixing, etc.), such systems will perform other important functions, such as measurement of conductivity (water salinity), temperature, depth as well as biological detection, electric charge collection, etc.

Nature of YRC activity will be highly interdisciplinary, as it will include research areas of materials, microfluidic mechanics, electronic components, circuits, numerical simulations and programming. Research topic of YRC is closely intertwined with implementation of existing projects of the program group Microstructures and Nanostructures.

YRC must have the ability to work professionally in international environment, which includes the basics of writing scientific articles and a good knowledge of English (B2 / C1). YRC is expected to be highly motivated, which includes self-initiative, innovation and reliability at work. YRC can look forward to integration into the LMSE team, and must therefore exhibit enthusiasm to work with other LMSE staff.

YRC will conduct his/her doctoral study within doctoral studies program of Electrical Engineering, University of Ljubljana.

5. Priloge, ki jih je treba priložiti ob prijavi *(Documents required to be submitted with the application)*:

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- kandidat z zaključenim magistrskim študijskim programom (2. bolonjska stopnja)
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  - priloga k diplomi / potrdilo o opravljenih obveznostih
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- kandidat, ki še ni zaključil študija na 2. stopnji
  (candidate who has not yet completed a Master's degree):
  - potrdilo o do sedaj opravljenih obveznostih z ocenami magistrskega študijskega programa, s katerim se bo kandidat prijavil na doktorski študij
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☒ **življenjepis** *(CV)*

☒ **motivacijsko pismo** *(motivation letter)*

☒ **opis dosedanjega sodelovanja pri raziskovalnem delu** *(description of the candidate's research work)*

☐ **osnutek idejne zasnove raziskovalnega dela** *(preliminary research proposal)*

☐ **priporočilno pismo** *(letter of recommendation)*

☐ **druge priloge** *(other attachments):*