IVA	**The Jacob Wallenberg Foundation grant for research and development in materials science**

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the Royal Swedish Academy of Engineering Sciences.
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Final Report

JWF-10/08

by

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October 2008

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Acknowledgements

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- The board of the Jacob Wallenberg Foundation for their generous award.
- The Royal Swedish Academy of Engineering Sciences and Mr Per Storm, Secretary to the Academy, for kindly arranging the donation.
- Mr Bengt Thulin of the SKF Group, Secretary to the Jacob Wallenberg Foundation, for his kind help in arranging the project's financial details, communications, and the author's trip to Sweden to present his work in October 2007.
- Mr Tom Johnstone, President and Chief Executive Officer of the SKF Group as well as chairman of the Jacob Wallenberg Foundation board. The author is grateful to Mr Johnstone for his invitation and kind hospitality in SKF's Club House in Slottsviken, Sweden, in October 2007.
- Dr Richard Sayles, Reader in the Department of Mechanical Engineering at Imperial College London, for kindly nominating the author for this award.

Summary

Dr Nikas was awarded a Jacob Wallenberg Foundation grant of 100,000 SEK (about 7,400 GBP) in May 2007 for his research and development in materials science (see letter in appendix 1). Due to the original letter being lost in the post, Dr Nikas was informed about the award with considerable delay in September 2007. He gladly accepted the grant (see response letter in appendix 2) and made an introductory presentation about his engineering research at the SKF's Club House in Slottsviken, Sweden, on the 30th of October 2007, invited by the SKF Group CEO and President Tom Johnstone (see invitation in appendix 3). The grant was finally credited in November 2007 (see payment credit advice in appendix 4).

During the period of the grant (November 2007 to October 2008), Dr Nikas was an Academic Visitor in the Tribology Group of the Department of Mechanical Engineering at Imperial College London without a salary. Thus, his only income was that provided by the grant, which was used for his own financial support and to progress in his research, according to the plan outlined in appendix 2 and accepted by IVA (see appendix 5).

The work completed by Dr Nikas during the one year of the grant can be summarized as follows.

(a) Authored one technical report (117 pages) for the European Union on the finite element analysis of surface coatings in rolling and fretting contacts. The report has been submitted to the EU.

(b) Authored two book chapters in two different books by invitation from Nova Science Publishers in the USA. A 46-page chapter on the tribology of reciprocating hydraulic seals and a 47-page chapter on the review of effects of solid contaminants in machine element contacts. These books will be published in the last quarter of 2008 and the first quarter of 2009, respectively.

(c) Authored three papers (one by invitation in a special Journal issue) and published in the IMechE Journal of Engineering Tribology. One paper deals with a novel lubrication mechanism involving two-phase fluids and porous bearings materials; the other two papers concern the finite element analysis of layered rolling and fretting contacts.

(d) Gave an invited lecture in an IMechE 1-day seminar in London on reciprocating seals.

(e) Continued the editorial work for a review book on recent developments in friction, lubrication and wear. The book, edited by Dr Nikas, will have nine chapters (five are currently ready for the publisher) with 12 contributors, University professors and doctors in tribology from the USA, UK, Japan, Sweden and Israel and very well known in the tribology community. The book is expected to be published in 2009. Dr Nikas' editorial work on the book commenced in June 2007.

(f) Submitted more than 50 reviews of papers in his role as referee in scientific Journals in tribology and mechanical sciences. Furthermore, as external referee and upon invitation by the Czech Science Foundation in the Czech Republic, Dr Nikas submitted reviews for two research-grant applications.

The previous tasks are described in the following sections.

1. Technical report for the European Union

The technical report was compiled by Dr Nikas in December 2007 for the European Union and the collaborators of the project code-named FOREMOST (Fullerene-based opportunities for robust engineering: Making optimised surfaces for tribology). Details of this project, Dr Nikas' research and his technical report are summarized next.

Public website: **www.foremost-project.org/**

Collaborators

A consortium of 31 companies and Universities in Europe. Among the participants were IonBond (UK and Switzerland), Fuchs (Germany), Nanomaterials (Israel), Renault (France), EADS (Germany), Rolls-Royce (UK), Goodrich (UK), CEA (France), VITO (Belgium), BAM (Germany), FZR (Germany), CNRS (France), Josef Stefan Institute (Slovenia), MFA (Hungary), NPL (UK), Stockholm University (Sweden), Uppsala University (Sweden), Linköpings University (Sweden), Newcastle University (UK), and Leeds University (UK). The project was co-ordinated by the Tekniker Technological Centre (Spain) and had a total cost of about 19 million Euros.

Sponsor: European Union (**project details on the EU website**).

Researcher from Imperial College London: Dr George K. Nikas

Supervisors for the part of the project at Imperial College London:

- Dr Richard Sayles (Imperial College London, Department of Mechanical Engineering).
- Mr Alberto Alberdi (Tekniker, Spain).
- Professor Staffan Jacobson (Uppsala University, Sweden).

Project duration (for the author's part): 18 months (2005-2007).

Project cost payable to Imperial College London: £209,000.

Technical report: A technical report was written by Dr Nikas for the European Union. The 117-page report contains 73 figures (including 225 diagrams), 16 tables, 13 detailed equations and 7 appendices. Of the 225 performance diagrams, 90 are for the rolling-contact analysis and 135 are for the fretting-contact analysis.

Summary

The main objective of Dr Nikas' work, which involved mathematical analysis and computational modelling, was the tribological performance mapping of rolling and fretting contacts of coated solids under dry and lubricated conditions.

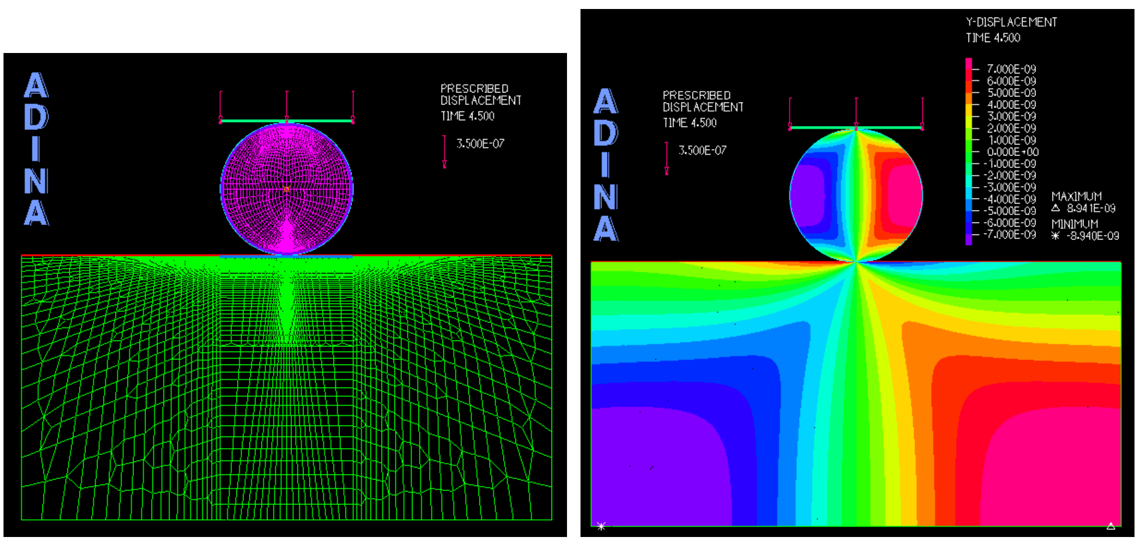
The tribological mapping involved the following tasks.

- Contact and subsurface stress analysis of rolling and fretting contacts of coated solids.
- Computation of frictional effects in dry and in simulated lubricated conditions.
- Study of failure and reliability issues.

- Estimation of the fatigue life of the coated components and comparison of the coated and uncoated surfaces to highlight the improvements.

Finite-element models were developed using the commercial software **ADINA**. The models deal with smooth surfaces and apply two-dimensional analysis (plane strain). For rolling contacts, this involved the contact between two coated, solid cylinders, and the contact of a coated cylinder with a flat, coated substrate. For fretting contacts, the model deals with a flat-rounded punch on a coated, flat substrate. Some examples are shown next, purely for demonstration purposes.

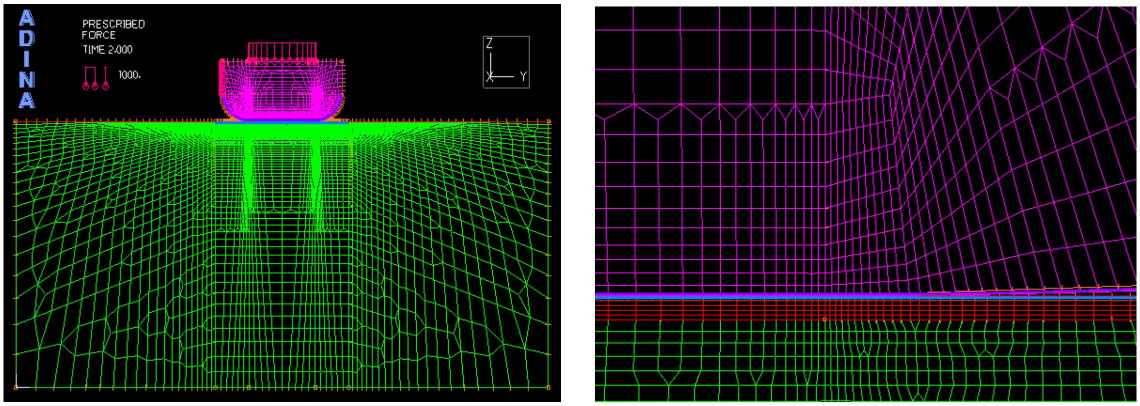
Figure 1(a) shows the finite-element mesh for a 2-d rolling contact of a coated cylinder on a coated substrate in plane strain. The mesh is intelligently constructed to be dense in the areas of interest and coarse in areas where accuracy is of less importance, such that computational speed is not compromised. This model contains approximately 21,000 to 33,000 solid elements with the minimum element size in the coatings equal to approximately 1 μm. Figure 1(b) shows the lateral displacement at some point during the loading of the roller. This work has applications in, for example, linear guidance systems and ball screw drives such as those produced by Fatronik, one of the project collaborators.



(a) **(b)**

Fig. 1. **(a)** FE mesh for the 2-d rolling contact of a coated cylinder on a coated substrate. **(b)** Distribution of lateral displacement in purely normal loading of the roller.

Figure 2(a) shows the finite-element mesh for the 2-d fretting contact of a flat-rounded punch on a coated substrate in plane strain. The mesh is again intelligently constructed to be dense in the areas of interest and coarse in areas where accuracy is of less importance, such that computational speed is not compromised. This model contains approximately 20,500 to 38,500 finite elements (depending on coating thickness), with the minimum element size in the coatings equal to approximately 1 μm near the two edges of the contact, which are the regions of stress concentration. Figure 2(b) shows the finite-element mesh at the right edge of the contact. This work has many applications, for example, turbine blade roots, spline couplings, bearing housings on rotating shafts, shrink fits and bolted parts, electrical contacts, etc.



(a) **(b)**

Fig. 2. **(a)** FE mesh for the 2-d fretting contact of a flat-rounded punch on a coated substrate. **(b)** Detail of the mesh at the right edge of the contact (coating shown in red colour).

2. Book chapter on the tribology of hydraulic reciprocating seals

On 15 October 2007, Dr Nikas received an invitation from Nova Science Publishers (New York, USA) to compile a chapter for a new book on tribology. Dr Nikas accepted the invitation and submitted a review chapter on reciprocating hydraulic seals on 3 March 2008. The details of this chapter and book are as follows.

Book chapter: **Research on the tribology of hydraulic reciprocating seals**. (46 pages, 147 references.)

Author: George K. Nikas

Where: second chapter in the book **Tribology Research Trends**; Editor: T. Hasegawa. **Nova Science Publishers**, Inc., NY, USA, 2008. ISBN: 978-1-60456-912-4. Publication date: fourth quarter of 2008.

Abstract

Hydraulic seals are found in industrial applications involving linear or rotary motion, as for example in hydraulic actuators. They are usually made of a polymeric material (for example, elastomer or “rubber”) or a combination of materials (composite seals, for example, elastomer and PTFE with glass fibres). Their shape varies from the typical rectangular cross-section with chamfered or rounded corners and the typical O-ring to hundreds of less conventional designs with complex geometries, although they all have the same basic function, which is the sealing of fluids, normally under relatively high pressure (typically up to 80 MPa) and with operating temperature ranging from subzero values (typically as low as –65 °C) to relatively high values of up to 200 °C, depending on

application. Low-pressure applications are also met when seals are used as wipers, as for example in tandem seal arrangements.

Theoretical research on sealing involves concepts and methods from elastohydrodynamics, contact mechanics, thermoviscoelasticity, adhesion and surface topography, in order to achieve good agreement with experimental results and industrial experience, yet this is still quite difficult to achieve because of the mathematical and numerical complexity of the problem. Proof of such difficulty is the fact that after more than 60 years of research in this field, fundamental aspects of the problem are still being tackled, for example, elastohydrodynamics with surface roughness effects, whilst making simplifying assumption about others, for example, treating seal mechanics in the frame of linear elasticity and ignoring frictionally induced, thermal effects.

The present chapter explores the progress and research trends in computational and experimental tribology of hydraulic, reciprocating, rod and piston seals. Topics include the solution of the elastohydrodynamic and contact mechanics problem of flexible polymeric and composite seals, the modelling of seal extrusion and anti-extrusion rings, seal elasticity and its effect on sealing performance, the modelling of tandem seals, rotary vane seals, transient effects in lubrication, as well as performance evaluation in terms of leakage, friction, extrusion and wear, followed by optimization. Experimental studies are also briefly discussed, together with a presentation of the difficulties in validating existing models and in producing realistic, reliable and consistent results. The review covers the period from the 1940s to 2008 and serves as a reference source for further study and development in this challenging field, from the original basic experimental rigs and archaic computers of mid 20th century to the sophisticated numerical methods and expensive experimental devices of the recent era.

3. Book chapter on the effects of solid contaminants in machine element contacts

On 24 January 2008, Dr Nikas received an invitation from Nova Science Publishers (New York, USA) to compile a chapter for a new book on reliability engineering. Dr Nikas accepted the invitation and submitted a review chapter on the detrimental effects of solid contaminants in machine-element contacts on 4 June 2008. The details of this chapter and book are as follows.

Book chapter: **Review of studies on the detrimental effects of solid contaminants in lubricated machine element contacts**. (47 pages, 151 references.)

Author: George K. Nikas

Where: first chapter in the book **Reliability Engineering Advances**; Editor: G. I. Hayworth. **Nova Science Publishers**, New York, USA, 2008. ISBN: 978-1-60692-329-0. Publication date: first quarter of 2009.

Abstract

Maximizing the life expectancy of machine elements in relative motion is the ultimate challenge faced by tribology researchers in industry and academia. However, despite the progress in materials science and lubrication methods, a great obstacle remains in achieving this goal, and that is the

presence of solid contaminants in lubricants. The entrainment of 1-100 μm debris particles in concentrated contacts such as in bearings, gears, cam-followers or seals, is associated with various damage modes such as surface indentation and abrasion, lubricant starvation and scuffing, high frictional heating etc. All of these refer to plastic deformations and are detrimental to the life of the machine elements involved and, obviously, to the machine itself.

This chapter contains a review of theoretical and experimental studies in the literature on the effects of debris particles in lubricated contacts, exploring the progress made in the last few decades. The studies cover the entrainment, entrapment and passage of debris particles through the contacts, and how this is affected by the operating conditions. Analytical, numerical and experimental studies are discussed in view of understanding the damage mechanisms involved in this process. This helps to improve the designs, depending on application requirements, aiming at minimizing the risks, maximizing life expectancy and, thus, improving engineering reliability in industrial, automotive and aerospace applications.

4. Journal paper on a novel lubrication mechanism

On 10 July 2007, Dr Nikas received an invitation from Professor M. Khonsari (Louisiana State University, USA), Associate Editor of the IMechE Journal of Engineering Tribology, to contribute a paper in a special issue of the Journal on granular lubrication. Dr Nikas accepted the invitation and prepared a paper on a novel lubrication mechanism involving two-phase fluids and porous bearing materials, based on a 12-month research project he had completed in 1998. The paper was peer reviewed and accepted for publication in the Journal. It was published in the sixth issue of 2008. Details are provided next.

Paper: **A study of lubrication mechanisms using two-phase fluids with porous bearing materials**.
Authors: Nikas, G. K., and Sayles, R. S.
Where: Proceedings of the Institution of Mechanical Engineers (IMechE), Part J: **Journal of Engineering Tribology**, 2008, **222**(J6), 771-783 (special issue on granular lubrication). Invited by the Guest Editor of that special issue, Professor M. Khonsari (USA). Available from **Professional Engineering Publishing**.

Abstract

A potential, novel lubrication mechanism involving two-phase fluids and porous bearing materials is examined in this study both theoretically and experimentally. Lubricating oils with a secondary particulate phase have been considered operating in oil-saturated porous media with the elements of the particulate phase acting as one-way valves on the pores, blocking and unblocking them, depending on the direction of contact load. The goal is to enhance the lubrication, mainly in starved contacts and in some “difficult” applications, as for example in big end bearings for marine engines. The theoretical part of this work deals with the mathematical analysis of an oil-saturated, porous slab, in contact with a solid sphere and lubricated with a two-phase oil containing thin and soft platelets. The problem is

analysed using Biot's theory of consolidation in porous media. A subsequent study deals with the effects of the maximum contact load, size and number of pores of the porous medium, elastic modulus of the medium, and the viscosity of the oil used to carry the particulate phase, on the lubrication performance of the system. Furthermore, a rig was built to study the concept on a macro-scale and the results are reported in the paper. Both the theoretical and the experimental work gave good indications that the concept works, at least in some cases. Potential problems with application of this lubrication mechanism have also been identified and are briefly discussed in the paper.

Some figures from this work

The theoretical model is chosen to comprise a ball on a porous slab, as depicted in Fig. 3. The slab is made of isotropic, porous material, and is, initially, completely saturated with oil. The ball is loaded by a normal, oscillating load *P*, and any pores contained in the contact circle of the ball and the slab are assumed blocked by platelets trapped between the two counterfaces. Thus, the said pores are impervious. The distribution of pores on the upper and lower surface of the slab is assumed random.

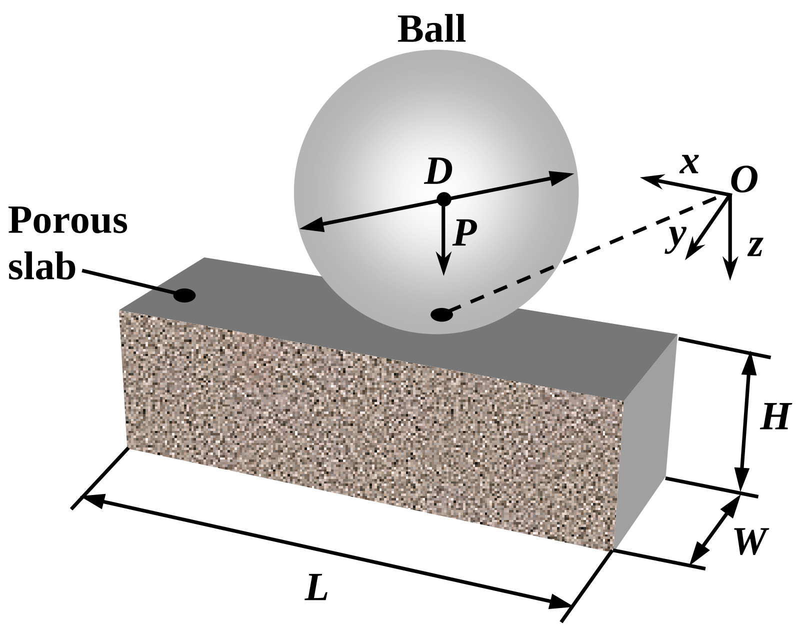


Fig. 3. Theoretical model: solid ball in contact with a porous, oil-saturated slab.

Figure 4 shows the (normalised) quantity of oil exchanged through the pores of the upper surface of the slab (upper graph) for sinusoidal load *P*. Looking at the fitting curve, it is clear that lubrication on the surface of the slab is improved by the oil exuded through the pores of the slab in time. The lower graph in Fig. 4 shows an important detail: the micro-undulations in oil delivery are caused by the dynamic opening and closing of the surface pores by the platelets.

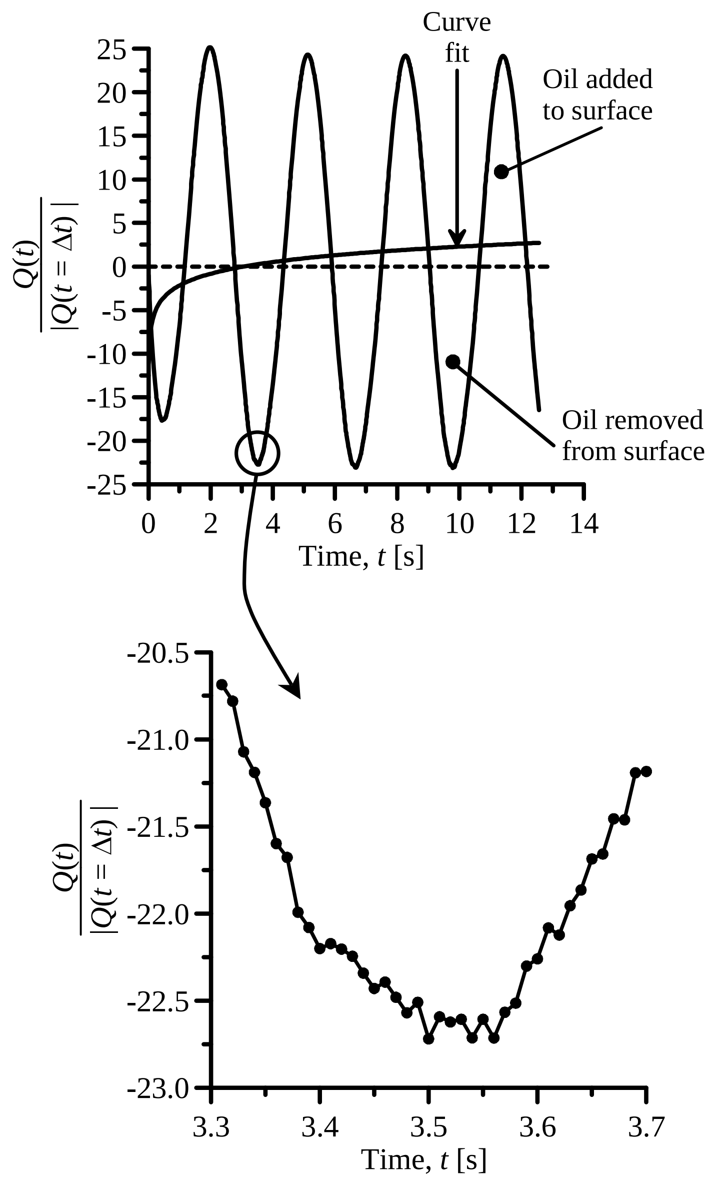


Fig. 4. Normalised quantity of oil exchanged through the pores of the upper surface of the slab (upper graph) for sinusoidal load *P*. The lower graph shows the micro-undulations in oil delivery, caused by the dynamic blockage of pores by platelets.

Similarly to Fig. 4, detailed results are presented in the paper about the effects of the maximum contact load, size and number of pores of the porous medium, elastic modulus of the medium, and the viscosity of the oil used to carry the particulate phase, on the lubrication performance of the system.

The experimental part of this study involved the design and construction of a rig to study the concept of lubrication enhancement macroscopically. Some pictures of the rig are shown in Fig. 5. The rig contains a porous plate fixed between two oil reservoirs. Only the top reservoir contains a known amount of the secondary particulate phase. This reservoir has pressure exerted within it by a solid piston, which is actuated by an Instron testing machine via a load cell. The Instron machine allows for both tension and compression to be applied accurately, and is linked to a computer interface with a graph plotter for easy data collection. Thus, the speed and displacement limits of the piston are set and the resultant load is measured.

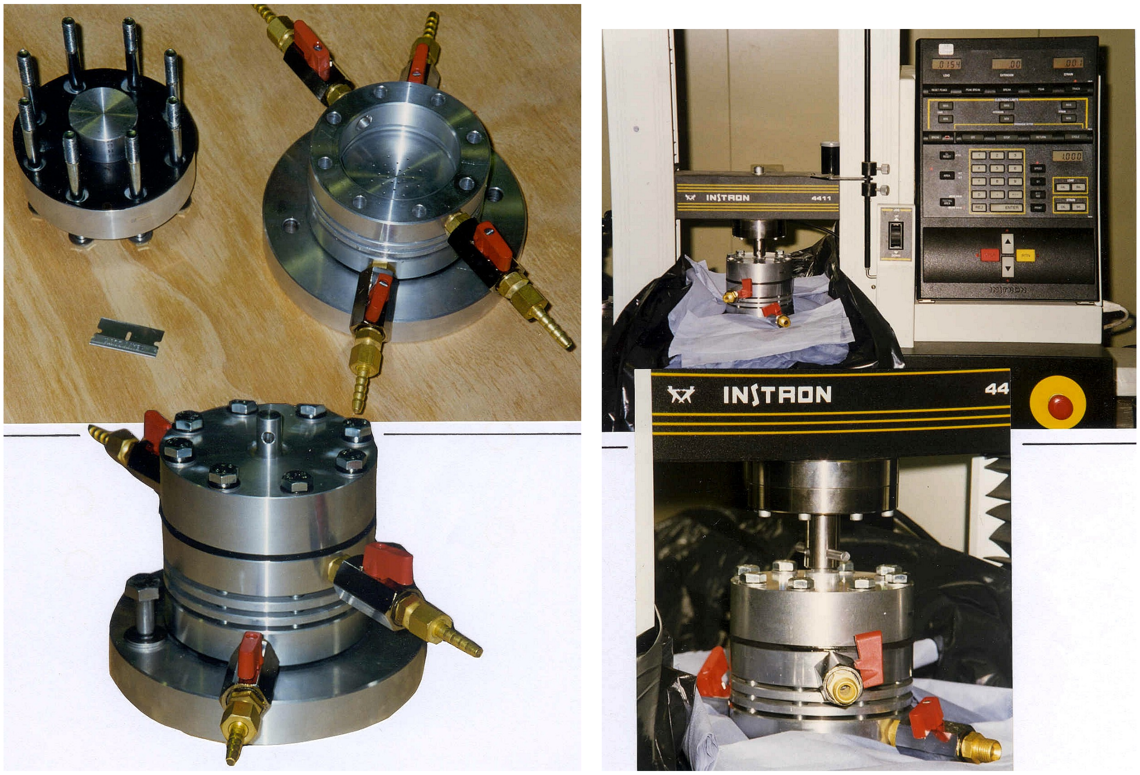


Fig. 5. Test rig (designed by research student Anthony Gibson-Watt at Imperial College London).

The experimental results confirmed the trends revealed by the theoretical model and proved the potential of this novel lubrication method.

5. Journal paper on the finite-element analysis of layered rolling contacts

Paper: Finite-element analysis of layered rolling contacts.

Authors: Nikas, G. K., and Sayles, R. S.

Where: Proceedings of the Institution of Mechanical Engineers (IMechE), Part J: **Journal of Engineering Tribology**, 2008, paper (JET438) accepted for publication.

Abstract

A fundamental, two-dimensional finite element analysis of coated surfaces in rolling contact is presented with detailed listing of all modelling steps. A large number of basic results from a parametric study has been derived, focusing on the stress analysis and the effect of coatings on the life expectancy of coated surfaces, without actually getting into the ambiguities of fatigue life evaluation. Parameters included in the study are the metallic coating thickness (from zero to 50 μm) and elastic modulus (from 180 to 240 GPa), the Coulomb friction coefficient (zero, 0.05 and 0.10) and the

endurance limit of the coated substrate. A generalisation involves the application of traction to simulate driving or driven wheels. The effect of that traction on the stress results is thoroughly examined. The set of results, summarized in a figure with nine diagrams, assists the quick selection of the optimum parameter values for maximising coating performance and minimising the risk of contact fatigue within the design limits used in the study. The model is realistic in that it does not use idealised load distributions in the rolling contact but actual geometrical solids in contact under normal operating conditions, letting the finite element analysis software resolve the loads and stresses, which are subsequently validated.

Some figures from this work

Figure 6 shows the finite-element mesh for the rolling contact of a coated cylinder on a coated substrate in plane strain (two-dimensional analysis). The mesh is intelligently constructed to be dense in the areas of interest and coarse in areas where accuracy is of less importance, such that computational speed is not compromised. This model contains approximately 21,000 to 33,000 solid, 9-node elements. The minimum element size in the coatings is equal to about 1 µm. A prescribed, downward vertical displacement is applied to a rigid line on the top of the roller to compress the roller on to the substrate. The vertical displacement is followed by the application of a uniformly distributed, horizontal force *F* on the axis of the roller. The horizontal force introduces tangential loading to the roller-substrate contact, emulating rolling conditions in this otherwise static contact. The arrangement gives effective rolling friction coefficients between zero and 0.1. Dry and lubricated contact conditions are emulated this way. The model was developed with the commercial software **ADINA** and was validated using established contact mechanics theories, showing excellent agreement, as detailed in the paper.

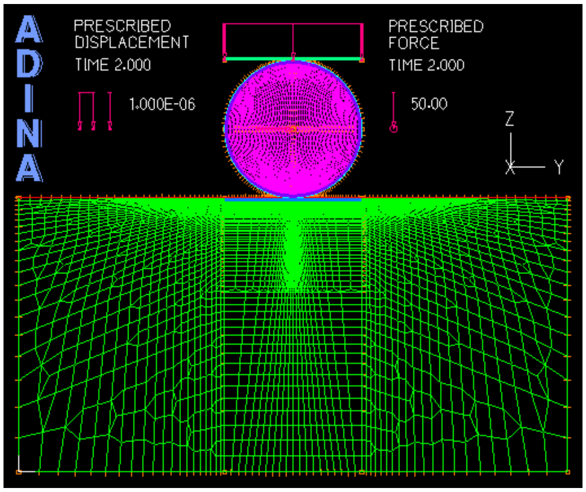


Fig. 6. Finite element mesh for the 2-d rolling contact of a coated cylinder on a coated substrate.

Figure 7 shows the effect of the substrate coating thickness and the elastic modulus of both coatings on the maximum absolute normal z-stress (see contour lines with labels in MPa) for F = 150 N, assuming the Coulomb friction coefficient between the contacting coatings is equal to 0.05. The vertical displacement of the roller is equal to 1 μm.

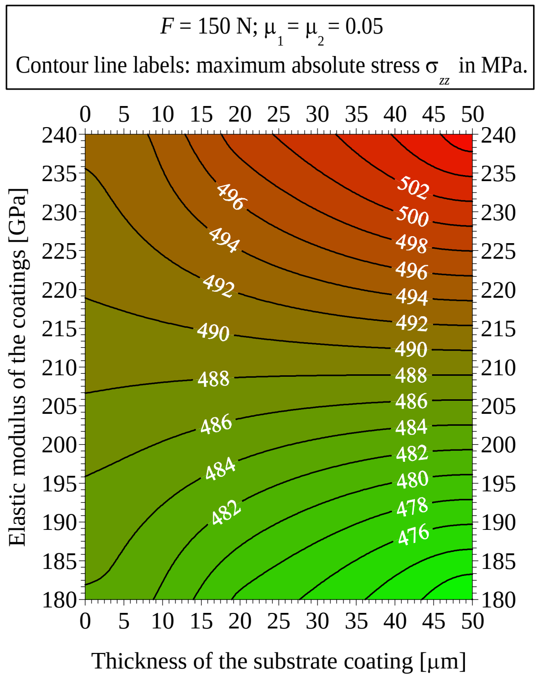


Fig. 7. Effect of the substrate coating thickness and coatings elastic modulus on the maximum absolute normal z-stress (see contour lines with labels in MPa) for F = 150 N, assuming a Coulomb friction coefficient between the contacting coatings equal to 0.05.

The paper contains a total of 60 performance diagrams. The results are summarized in a figure with nine diagrams, which facilitates the selection of the optimum parameter values for maximising coating performance and minimising the risk of contact fatigue within the design limits used in the study.

6. Journal paper on the finite-element analysis of layered fretting contacts

Paper: Surface coatings and finite-element analysis of layered fretting contacts.

Authors: Nikas, G. K., and Sayles, R. S.

Where: Proceedings of the Institution of Mechanical Engineers (IMechE), Part J: **Journal of Engineering Tribology**, 2008, paper (JET441) accepted for publication.

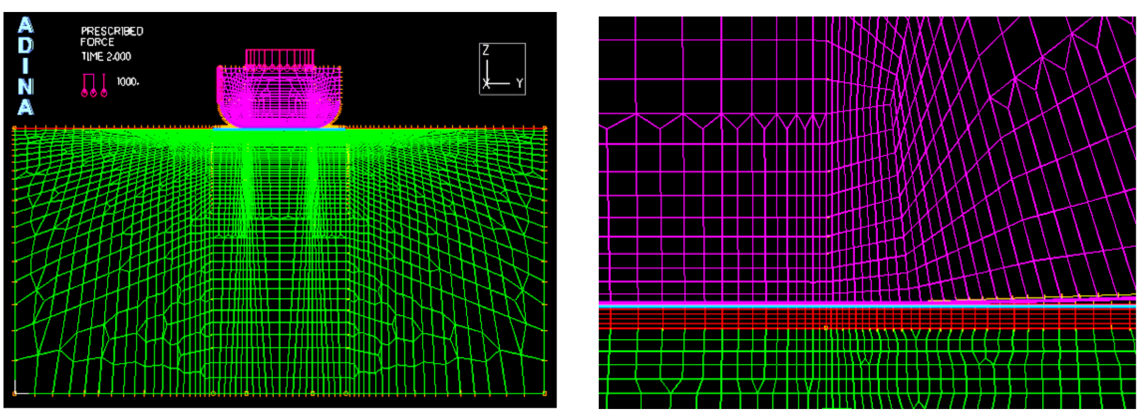
Abstract

A fundamental, two-dimensional finite-element analysis of a coated, flat surface in fretting contact with a flat-rounded punch is presented with detailed listing of all modelling steps. A large number of basic results from a parametric study has been derived, focusing on the stress analysis and the effect of coatings on the life expectancy of the coated solid, without actually getting into the ambiguities of life

evaluation. Parameters included in the study are the metallic coating thickness (5, 20, and 50 μm) and elastic modulus, the endurance limit of the coated substrate and the normal and tangential loads applied. A summary of the stress-analysis results is presented in a figure with nine diagrams, which assists the quick selection of the optimum parameter values for maximising coating performance and minimising the risk of fatigue within the design limits used in the study. The model is realistic in that it does not use idealised load distributions in the fretting contact but actual geometrical solids of finite dimensions in contact under normal operating conditions, letting the finite-element analysis software resolve the loads and stresses, which are subsequently validated.

Some figures from this work

Figure 8(a) shows the finite-element mesh for the two-dimensional fretting contact of a flat-rounded punch on a coated substrate in plane strain. A normal load is applied on the upper surface of the punch, followed by a horizontal load exerted to the left side of the punch to simulate fretting conditions. The mesh is intelligently constructed to be dense in the areas of interest (such as at the highly-stressed contact edges) and coarse in areas where accuracy is of less importance, such that computational speed is not compromised. This model contains approximately 20,500 to 38,500 finite elements, depending on coating thickness, with the minimum element size in the coatings equal to approximately 1 μm near the two edges of the contact, which are the regions of stress concentration. Figure 8(b) shows the finite-element mesh at the right edge of the contact. The model was developed with the commercial software **ADINA** and was validated using established contact mechanics theories, showing excellent agreement, as detailed in the paper.



(a) **(b)**

Fig. 8. **(a)** Finite-element mesh for the fretting contact of a flat-rounded punch on a coated substrate. **(b)** Detail of the mesh at the right edge of the contact (coating shown in red colour).

An example of the results in the paper is presented in Fig. 9. Figure 9 shows the effect of the substrate coating thickness and elastic modulus on the maximum effective (von Mises) stress for normal load P = 5000 N/m and horizontal load Q = 250 N/m (Q/P = 0.05), assuming that the Coulomb friction coefficient is equal to 0.2 in the central, stick region of the contact, and equal to 0.6 in the outer, slip regions of the contact.

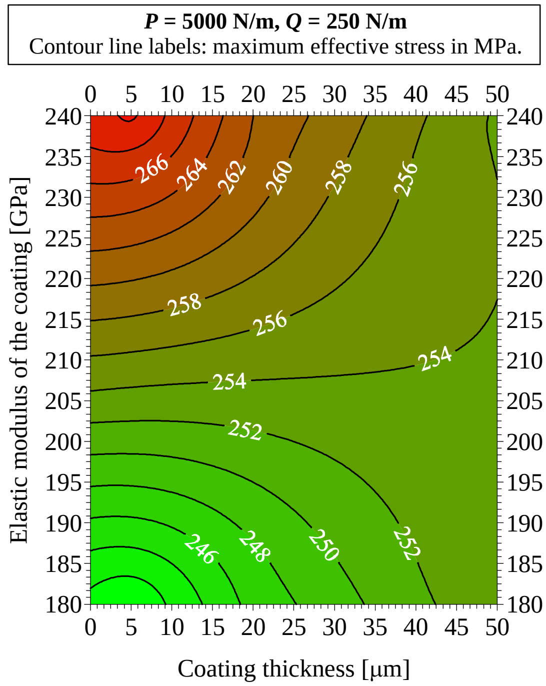


Fig. 9. Effect of the substrate coating thickness and coatings elastic modulus on the maximum effective (von Mises) stress (see contour lines with labels in MPa) for P = 5000 N/m and Q = 250 N/m.

The paper contains a total of 63 performance diagrams. The results are summarized in a figure with nine diagrams, which facilitates the selection of the optimum parameter values for maximising coating performance and minimising the risk of contact fatigue within the design limits used in the study. This work has many applications, for example, turbine blade roots, spline couplings, bearing housings on rotating shafts, shrink fits and bolted parts, electrical contacts, etc.

7. Invited lecture in an IMechE seminar on reciprocating seals

On 22 February 2008, Dr Nikas received an invitation from Professor R. Dwyer-Joyce (University of Sheffield, England) on behalf of the Institution of Mechanical Engineers (IMechE, UK) to give a lecture in a 1-day seminar on reciprocating seals organized by IMechE. Dr Nikas accepted the invitation and made his presentation in the seminar on 25 June 2008. The seminar attracted 54 delegates. Dr Nikas' paper was included in the proceedings of the seminar. Brief details are given next.

Paper: Fundamentals of sealing and tribology of hydraulic reciprocating seals.

Author: George K. Nikas

Where: Proceedings of the 1-day seminar "Focus on Reciprocating Seals" (organised by the Tribology Group of the Institution of Mechanical Engineers (IMechE), London, England, 25 June 2008). A copy of the paper in PDF format can be downloaded from
http://www.imperial.ac.uk/tribology/Nikas/Nikas_IMechE_25-06-2008.pdf .

Abstract

The paper examines some fundamental performance and tribological issues of hydraulic reciprocating seals. Topics include the solution of the elastohydrodynamic and contact mechanics problem of polymeric and composite seals, the modelling of seal extrusion and anti-extrusion rings, seal elasticity and its effect on sealing performance, modelling of tandem seals, rotary vane seals, transient effects in lubrication, as well as performance evaluation in terms of leakage, friction, extrusion and wear, followed by optimization.

8. Editorial work on a new tribology book

Dr Nikas has continued his editorial work on a review book on recent developments in friction, lubrication and wear. The book, edited by Dr Nikas, will have 9 chapters (currently, 6 are ready for the publisher) with 12 contributors, all of whom are well-known University professors and doctors in tribology from the USA, UK, Japan, Sweden and Israel. The main topics involve elastohydrodynamic and thin-film lubrication, rolling element bearings, surface coatings, thermodynamics, micro and nano tribology. The book is expected to be published in 2009. Dr Nikas' editorial work on this book commenced in June 2007.

9. Reviewing of Journal papers and research-grant applications in tribology

Dr Nikas has continued his work as peer reviewer of Journal papers and research-grant applications. During the period of the Jacob Wallenberg Foundation grant, Dr Nikas submitted more than 50 reviews of papers to the following Journals.

- **Journal of Tribology** (American Society of Mechanical Engineers, USA)
- **Journal of Engineering Tribology** (Institution of Mechanical Engineers, UK)
- **Tribology Transactions** (Society of Tribologists and Lubrication Engineers, USA)
- **Journal of Mechanical Engineering Science** (Institution of Mechanical Engineers, UK)
- **Tribology International** (Elsevier)
- **Journal of Power and Energy** (Institution of Mechanical Engineers, UK)
- **Journal of Aerospace Engineering** (Institution of Mechanical Engineers, UK)
- **Journal of Automobile Engineering** (Institution of Mechanical Engineers, UK)
- **TriboTest** (Wiley)
- **Lubrication Science** (Wiley)
- **Applied Mathematical Modelling** (Elsevier)

Finally, as external referee and upon invitation by the Czech Science Foundation in the Czech Republic, Dr Nikas submitted reviews for two research grant applications.

Appendix 1

Original letter of the award

THE JACOB WALLENBERG FOUNDATION

31 May 2007

Dr George Nikas
Imperial College London
Mechanical Engineering Department
Tribology Group (Room 891)
Exhibition Road
London SW7 2AZ
England

Dear Dr Nikas,

The Jacob Wallenberg Foundation

The Royal Swedish Academy of Engineering Sciences is responsible for the Jacob Wallenberg Foundation established 1971 by AB SKF. It supports research in the field of Materials Science by giving grants to persons engaged in research or development.

The board of the Jacob Wallenberg Foundation is pleased to inform you that it has decided to grant you the sum of 100.000 SEK for your research and development in the field of material science.

A brief interim report of the progress made should be submitted to the board of the Foundation within one year. A brief final report should be submitted within two years and should be accompanied by a financial report showing the expenditures covered by the grant.

The results achieved within the terms of the award should be published in an appropriate manner. The Foundation will not make any claims to inventions arising from the work financed by its contribution.

We would kindly ask you to inform IVA, Mr Per Storm, Secretary to the Academy, as soon as possible, whether you are willing to accept the grant on the terms outlined above and how you plan to spend it. The grant will then be made available to you according to your instructions.

On behalf of the Jacob Wallenberg Foundation,

Lena Treschow Torell
President
Royal Swedish Academy of Engineering Sciences

Bengt Thulin
Secretary to the Foundation
SKF Group

Postal address	Visiting address	Telephone	Fax	E-mail
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Appendix 2

Dr Nikas' response to the letter about the award (per appendix 1)

4 October 2007

Mr Per Storm
Secretary to the Academy
c/o IVA, Box 5073
S-102 42 Stockholm
Sweden

RE: Jacob Wallenberg Foundation grant

Dear Mr Storm,

I refer to your letter dated 31 May 2007 with which you informed me of the Academy's decision to grant me the sum of 100,000 SEK for my research in the field of materials science.

I am very sorry for the delay in responding to your letter. As you were recently informed by Bengt Thulin from SKF, I never received your original letter sent to Imperial College London and it was only through SKF CEO Tom Johnstone's invitation to me to give a lecture at SKF on the 30th of October as one of the Jacob Wallenberg Foundation awardees that I found out about this! Following Bengt Thulin's communication with you to explain the situation, I received your second letter sent to my home address on the 27th of September 2007.

I am honoured by the Academy's generous offer and I am very pleased to accept the grant on the terms outlined in your letter.

My research in the Mechanical Engineering Department at Imperial College London since 1994 involved several topics in the fields of Tribology and Contact Mechanics, related to lubrication, friction and wear. I have also collaborated with SKF and Technical Director Prof. Stathis Ioannides on research projects and publications.

My research plans, in relation to the Academy's grant, will focus on some or all of the following research projects, which I have been running in parallel for several years (listed below in order of priority).

(1) Mathematical modelling of the effects of lubricant contamination in machine element contacts. Expansion of my existing models on various damage modes (thermomechanical, contact fatigue, abrasion, scuffing) attributed to debris particles. I have been at the frontier of this field with several Journal papers published since 1996.

(2) Finite Element Analysis of thin surface coatings in rolling/sliding and fretting contacts. I have recently completed an 18-month research project funded by the European Union on this subject, involving many European industrial and academic partners, and I am in the process of reporting on my results and proceed with publications. I wish to continue my research in this area with the aid of the grant.

(3) I have also been at the frontier of sealing research and modelling, specifically for reciprocating seals, with funded research projects from major manufacturers (including Swedish Trelleborg) and a significant number of Journal publications since 2000. I will continue my research in this field.

(4) I am also working on hydrodynamic and gas, thrust and journal bearing research and modelling, which I plan on publishing in due time.

(5) Finally, I have completed two 18-month funded research projects on the mathematical modelling of Infinitely Variable Transmissions, involving elastohydrodynamics and mechanics of rolling-sliding-spinning concentrated contacts with subsurface stress analysis and fatigue life calculations.

I wish to continue my research in this area and I often utilize several of the models I have developed here on other research projects.

My work is primarily on the mathematical analysis and computational modelling on which I have expertise for 15 years, with 10 research projects (total funding in excess of 1 million EUR), over 35 publications (including 7 technical reports), and at least 10 complex computer programs I developed, some of which are registered to industrial companies that have funded my research over the years. All of those are detailed in my website and CV.

Therefore, my research "tools" involve computer hardware and software, as well as books. My projected main costs for the grant are for

(a) computing equipment; (my models are usually very computationally demanding (e.g. some models take several days of CPU time on my 1.5 GHz PC) and this has always been an obstacle in my work));
(b) computer software licenses, for example FEA academic license on my ADINA FEA software which expires in January 2008 and other mathematical and scientific graphics software such as Mathematica, FORTRAN compiler, etc;
(c) books on tribology, mechanics and mathematics.

The above list does not rule out the possibility of using some money on funding experimental research at Imperial College London, possibly on number (2) from the list of my projects as explained earlier, as well as on a novel lubrication mechanism for which I just submitted a paper for publication and for which we have done theoretical and experimental work in my research Group. For experimental work, I will collaborate with Dr Sayles, Reader in the Mechanical Engineering Department at Imperial College and my colleague since 1994, recipient of the Jacob Wallenberg Foundation grant in 2002.

I hope the previous details satisfy your initial request for information on grant spending. Naturally, all papers published and based on this research will have the Jacob Wallenberg Foundation and the Royal Swedish Academy of Engineering Sciences acknowledged.

I will be pleased to receive further guidelines on this grant, including costs claim procedure and timing. To avoid any delay and potential communication problems, **please use the postal address shown below for all correspondence.** As I am often travelling, the fastest way to reach me is by e-mail to **g.nikas@imperial.ac.uk**

Once again, I am sincerely thankful for your kind and generous offer.
Yours sincerely,

George Nikas

Dr George K. Nikas
3 Princes Mews
Hounslow
TW3 3RF
ENGLAND

Tel. (answering machine) & Fax: +44-(0)2085706257
E-mail: g.nikas@imperial.ac.uk
Website: http://www.imperial.ac.uk/tribology/george.htm

Appendix 3

Invitation to Dr Nikas by Mr Tom Johnstone, SKF Group President and CEO

Tom Johnstone
President and CEO

SKF

2007-08-30

Dr. George Nikas
Imperial College London
Mech Eng Dept, Tribology Group
(Room 891)
Exhibition Road
London SW7 2AZ
England

Jacob Wallenberg Foundation Seminar
30th October, 2007

Dear Dr. Nikas,

As one of the five Jacob Wallenberg awardees 2006/2007 I would like to invite you as speaker at a Jacob Wallenberg Foundation seminar in the afternoon of 30th October, at SKF's country club, Slottsviken, just outside Gothenburg.

The aim is to establish a good contact with you and learn more about your research area which can be of interest for SKF and possible further projects.
SKF will invite internal experts in the field of material science and research management. Proposed time for you lecture is 30 minutes.

I would be very pleased if you could attend this seminar. Please respond to Bengt Thulin (bengt.thulin@skf.com) before 15th September. Bengt will also answer any questions you may have. SKF will cover your expenses.

Best regards,

Tom Johnstone

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Appendix 4

Payment credit advice (bank transfer of the grant to Dr Nikas)

[redacted]

006968/008981/505

DR G NIKAS
3 PRINCES MEWS
HOUNSLOW
TW3 3RF

PAYMENT CREDIT ADVICE

Our ref: IBCSE2I07479385
Your ref:
Date: 9th November 2007
Delivery ref: 071109HANDSESSBXXX1942608287

In accordance with instructions received, we have arranged for your account to be credited.

Beneficiary name: DR GEORGE K NIKAS
Account: [redacted]
Amount credited: GBP 7,392.35

Value date: 13th November 2007

By order of:
STIFTELSEN JACOB WALLENBERGS FOND
BOX 5073
102 42 STOCKHOLM

On instructions from:
SVENSKA HANDELSBANKEN
11, BLASIEHOLMSTORG
STOCKHOLM
SWEDEN

Reference:
13278083244RS

Payment details:
J Wallenberg Foundation grant

Transactional information:

Amount received:	SEK 100,000.00
Rate:	13.5147
Currency exchange contract:	
NWB commission charges:	GBP 7.00
	The payment amount has been reduced

Funds can be reclaimed by the Bank up to 9.00 AM on the value date

Sheet 1 of 1

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Appendix 5

E-mail of acceptance of Dr Nikas' plans on the grant, as detailed in appendix 2.

Subject: Jacob Wallenberg Foundation grant

Date: Mon, 22 Oct 2007 14:19:00 +0200

From: annmargret.back@iva.se

To: g.nikas@imperial.ac.uk

Per Storm thank you for the letter of October 4 with information about your research plans as to the grant, which is fully accepted from our side. So please inform us about a suitable bank account and we will transfer the money to you as soon as possible.

Sincerely,
Ann-Margret Back, Assistant
IVA, Royal Swedish Academy of Engineering Sciences
annmargret.back@iva.se