CCGEX 2011-2013

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Projektnr 33834-1

Energimyndighetens titel på projektet – svenska Kompetenscentrum inom förbränningsmotorers gasväxling, KCGEx	
Energimyndighetens titel på projektet – engelska	
Ev. Energimyndighetens program [Klicka här och skriv]	Tidplan (2010)2011-2013
Total projektkostnad 63 000 000kr	Energimyndighetens andel av kostnaden i %/kr 33% / 21 000 000kr
Ev. rapporttitel hos stödmottagaren [Klicka här och skriv]	Ev. rapportnr hos stödmottagaren [Klicka här och skriv]
Universitet/högskola/företag KTH	Avdelning/institution Maskinkonstruktion
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Nyckelord: 5-7 st Competence center gas exchange, CCGEx, gasväxling, turbo, förbränningsmotor, strömningssimulering, akustik modellering, EGR, WHR	

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Slutrapport

Period 1

2011-2013

Competence Center Gas Exchange

CCGEx

Sammanfattning

Perioden 2011(2010)-2013 var den första finansieringsperioden för det nya kompetenscentrumet för gasväxling inom sveriges tre samarbetande förbränningsmotorcentrum. Kompetenscentrum för gasväxling CCGEx (Competence Center Gas Exchange) var en omstart av det tidigare gasväxlingscentrumet CICERO (2006-2009) med i huvudsak samma kompetens/forskningsområde men med något ändrad fokus, organisation och styrning. Industrins engagemang och forskningens industrikoppling ökades genom tillsättande av en föreståndare utlånad av industrin. Vidare utarbetade under 2009 styrelserna för CERC, KCFP och CICERO tillsammans med representanter för CTH, LTH, KTH och Energimyndigheten en ny princip för samordning mellan kompetenscentra. I samråd beslutade parterna att införa en Strategi och Samordningsgrupp (SoS) inför den nya avtalsperioden 2010 - 2013. De tre kompetenscentrumen samordnades i detta under samlingsnamnet Swedish Internal Combustion Engine Consortium – SICEC.

Arbete har lagts på att uppdatera vision/mission samt utforma, visualisera och förankra en strategi och ett arbetssätt som syftar till att få en gemensam förståelse mellan centrumets alla parter gällande centrumets mål, leveranser samt fortsatt säkra den akademiska höjden och nyttan.

Centrumledningen har till del förändrats för att skapa en struktur med tydliggjorda uppgifter och befogenheter att utnyttja den kompetens som finns tillgänglig i centrumet, stärka samverkan mellan centrets olika vetenskapliga discipliner samt renodla syften med möten och forum.

CCGEx forskning under perioden har omfattat system, komponenter samt grundläggande fysikaliska strukturer som pulserande strömning i rör och akustik i komponenter. Ambitionen under perioden har varit att gå ifrån ett upplägg där många områden täcks med enstaka aktiviteter/studenter till att begränsa antalet forskningsområden, ambitionen är cirka tre stycken, för att i de områden där CCGEx är aktiva kunna lägga mer resurs. Pågående doktorandprojekt från det tidigare CICERO har i stort sett lyfts över för att säkra kontinuitet för dessa.

Totalt har 7 doktorsavhandlingar, 8 licentiatavhandlingar och 13 Master of Science arbeten presenterats.

Ett första nytt/förnyat forskningsområde, compressor off desing operation, har initierats, beretts och bemannats inom centrumet för att skapa fokusering och skapa synergier mellan i centrumet tillgängliga kompetenser och resurser.

Summary

This report covers the period of 2011(2010)-2013 which was the first period of operation for the new third Swedish competence centre in internal combustion engine. The centre complements the other two (KCFP and CERC) by focusing on the gas exchange process, system and phenomena connected to this. The Competence Centre Gas Exchange, CCGEx, was a restart of the previous gas exchange centre CICERO which was operating 2006-2009. The CCGEx resources and competence are mostly the same as for the previous centre, but with an update direction of research, organisation and management. The industry involvement and a more direct connection between industry need and research direction is enhanced by the appointment of a centre director provided and funded by the industry.

In addition to these changes the centre boards of the three centres KCFP, CERC, with the cooperation of the universities (LTH, CTH and KTH) , CICERO did during 2009 form a Swedish Internal Combustion Engine Consortium, SICEC. The goal of SICEC has been to unify the research profiles at the three university centers. The idea is to generate and continuously update a unified, nationwide research strategy with each university taking a part, to provide better and more organized support to industry and society.

A fair amount of work has been spend on updating and analyse the vision/mission of the centre and to formulate, visualize and establish a strategy and organisation to support these visions and goals while maintaining the research quality from previous centre. The centre management have been adjusted in order to clarify and formulate the division of responsibility and authority for meetings and forum within the centre to utilise the available competences within the centre.

The research activities during the period include engine systems, components aswell as studies of fundamental physics phenomenon such as pulsating flow in pipes and acoustics generation and transmission in components. The ambition has been to transfer from a large number of areas covered by individual projects/students into limit the number of research areas in order to be able to focus more resources and disciplines in the same area. Already ongoing projects from previous CICERO have been incorporated as is within CCGEx to ensure continuity for these.

In total 7 PhD thesis's, 8 licenciate thesis's and 13 MSc thesis have been presented during 2011-2013.

A first pilot research focus area, compressor off design, has been intiated, prepared and resources have been assigned. The ambition is this will form a basis for more focused work and to establish a better use of resources, academic as well as industrial, with the centre.

Innehållsförteckning

Inledning

Den svenska motorindustrin har varit tidiga med överladdning och är starka inom detta område ur ett internationellt perspektiv. Betydelsen av detta område ökar med nya förbränningssystem som kräver höga EGR-halter och laddtryck. Ventilsystem med variabla öppnings- och stängningstider och lyft kommer mer och mer. För att behålla industrins konkurrenskraft är det viktigt med kontinuerlig kompetensförsörjning inom området. Det gäller såväl sakkunskap som forskare med relevant kompetens. Området gasväxling och överladdning är specifikt för CCGEx och täcks inte upp av något annat svenskt kompetenscentrum.

Ett kompetenscentrum i förbränningsmotorteknik (CICERO) startades formellt 2006-01-01 med Energimyndigheten, svensk fordonsindustrin och KTH som partners. Kompetenscentret var huvudsakligen verksamt inom området ”gas management” och hade syftet att kombinera kompetenser inom grundläggande strömningsmekanik inklusive akustik med praktisk förbränningsmotorkunskap. CICERO upphörde i slutet av 2010.

CCGEx efterträder CICERO, med samma ingående avdelningar, men med reviderad inriktning och ledning som ett resultat av de rekommendationer som framkom i utvärderingen av CICERO 2009. I CCGEx ingår avdelningarna förbränningsmotorteknik (KTH Maskinkonstruktion), Marcus Wallenberg Laboratoriet för Ljud och Vibrationsforskning (KTH Farkost och Flyg) och strömningsfysik och tillämpad strömningsmekanik (KTH Mekanik). Dessa avdelningar samverkar inom CCGEx. I CCGEx har den förbränningsmotortekniska kopplingen stärkas jämfört med CICERO. Föreståndarpositionen har uttalat placerats på förbränningsmotorteknik.

För att svara upp mot den kritik och förbättringspunkter som framfördes vid utvärderingen 2009 samt den förändring i inriktning och arbetssätt som presenterades i ansökan om uppstart av CCGEx 2010 har under den nu avslutade perioden ett omfattande arbete kring diskussion och förankring av målbilden och rollerna inom centrument genomförts. Resultatet av denna process presenteras i form av en omarbetad Vision, Syfte och Strategi beskrivning, vilken presenteras i följande sektion.

Vision

Genom att bedriva världsledande gasväxlingsrelaterad forskning ska CCGEx vara en självklar partner för såväl akademi som industri.

CCGEx ska genom sitt arbete främja medlemsföretagens övergång till ett mer kunskaps- och beräkningsbaserat arbetssätt med mindre beroende av protyptestning och lösningar byggda på praxis.

CCGEx ska genom forskning och tydligt samarbete mellan akademi och industri förmedla en positiv och inspirerande bild av de intressanta utmaningar och möjligheter som uppstår vid mötet av de i centrumet delaktiga ämnena.

Syfte

CCGEx:s syfte är att utföra akademisk forskning med högsta kvalitet inom området förbränningsmotorers gasväxling i nära samverkan med fordonsindustrin och därmed bidra till ett effektivt, hållbart och konkurrenskraftigt transportsystem. Genom att utnyttja avancerade analys-, mät- och syntesmetoder ska den fysikaliska förståelsen öka för grundläggande relevanta fenomen. Genom denna ökade förståelse kommer forskare inom CCGEx att kunna identifiera nya tekniska möjligheter och lösningar inom gasväxling, EGR-system, överladdning och efterbehandlingssystem.

CCGEx ska stödja svensk fordonsindustri med relevant forskning huvudsakligen riktat mot tidsperspektivet 10-20 år. Projekt och uppdrag med kortare tidsperspektiv hindrar inte det övergripande tidsperspektivet.

CCGEx ska rekrytera och utbilda framtida ledare och experter inom förbränningsmotorutveckling och forskning i nära samverkan med fordonsindustrin. Dessa ska tränas i grundläggande förbränningsmotorteknik såväl som att utföra kvalitetsforskning med hjälp av avancerade metoder. Bredden av metoder erhålls genom samarbete med forskare inom centret där tre akademiska ämnen (förbränningsmotorteknik, strömningsmekanik samt akustik) är representerade.

Mål

CCGEx övergipande mål är bli ett ledande nationellt och internationellt centrum kring gasväxling som stödjer industrins utveckling mot ett mer kunskaps- och beräkningsbaserat arbetssätt.

Forskningskompetenser

CCGEx är uppbyggt av tre forskningsgrupper som representerar de vetenskapsområden som centret omfattar: *Förbränningsmotorteknik*, Inst för Maskinkonstruktion, skolan för industriell teknik och management (ITM); *Strömningsmekanik*, Inst för Mekanik samt *Marcus Wallenberg Laboratoriet för ljud och vibrationsforskning* (MWL) bägge vid skolan för Teknikvetenskap (SCI). Totalt har fem professorer samt cirka tio yngre forskare från dessa tre grupper att varit aktiva inom centret, se www.ccgex.kth.se. Den vetenskapliga kvaliteten hos deltagande forskare är hög. De två grundvetenskapliga delarna inom centret, Mekanik samt Akustik (MWL), rankades t.ex. vid VR:s utvärdering av Mekanikområdet i Sverige med betygen ”outstanding” respektive ”excellent”. Beträffande hela området ”Mechanical engineering” rankas KTH som nummer 28 i världen och nummer 8 i Europa.

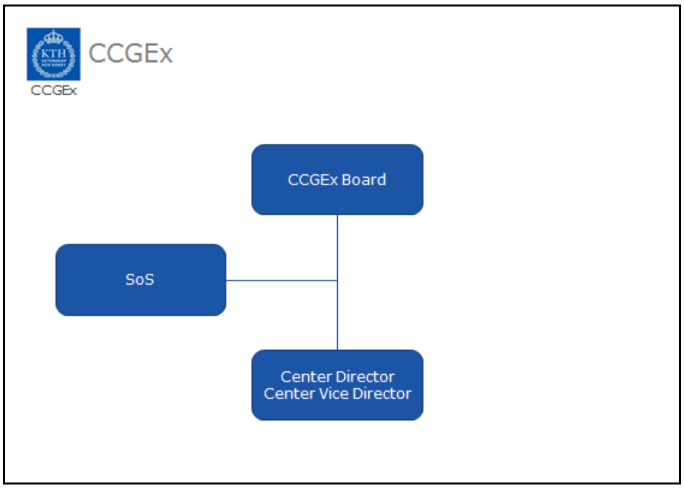
Centralt för CCGEx är det moderna motorlaboratoriet med fyra motorprovceller med tekniker och verkstadssupport som finns vid avdelningen för förbränningsmotorteknik samt det särskilda turbolaboratoriet (CICERO) som byggts upp under det tidigare centrets period. Detta turbolaboratorium är en unik resurs som medger detaljerade studier av samverkan mellan pulserande gasflöden och turboaggregat. Här kan också nämnas möjligheterna att i detalj kartlägga de akustiska egenskaperna.

Vid KTH Mekanik finns kompetens inom avancerad CFD inklusive turbulensmodellering i kompressibla och instationära strömningsfält med och utan kemiska reaktioner. Dessutom finns ett avancerat laboratorium med kompetens för avancerade strömningsmätningar (t.ex. varmtrådsanemometri, LDV, PIV och sliroptik). Vid Marcus Wallenberg Laboratoriet för Ljud- och Vibrationsforskning (MWL) som tillhör institutionen Farkost och Flyg, finns en grupp som sedan mer än 20 år har arbetat med akustisk modellering av insugnings- och avgassystem för förbränningsmotorer. Vid MWL finns också utmärkta experimentella resurser och erfarenhet av speciella mätmetoder för analys av ljudfält i strömmande media.

Organisation

Centrumet består totalt av fem huvudparter:
Akademin – KTH
Svenska staten – Energimyndigheten
Industriparter – Scania CV, Volvo Cars, Volvo GTT, (SAAB)

Styrning, Figur 1, av centrumet sker via styrelsen, där akademin och de tre industriparterna är representerade med en röst var och energimyndigheten har rätt till representation utan rösträtt. Styrelseordförande, med två röster, är SICEC och gemensam för alla tre motorforskningscentrumen.



Figur 1 CCGEx styrning

Styrelsen har också en stödfunktion i och med Strategi och Samordningsgruppen vilken har till syfte att överblicka och underlätta samordning och samarbete mellan kompetenscentrumen.

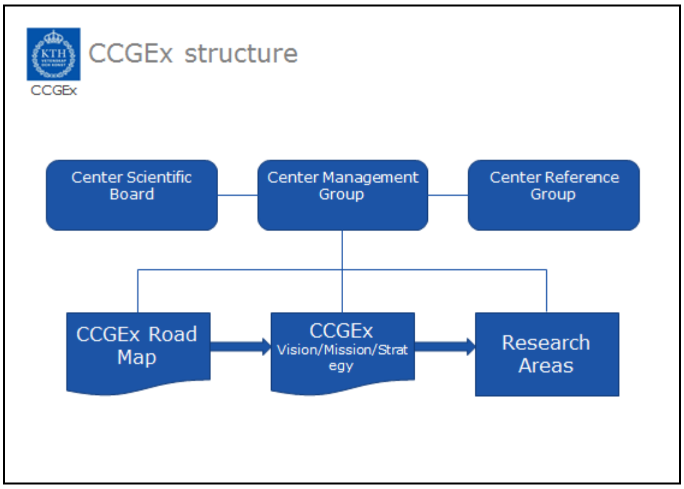
Ledningsuppdraget för centrumet och föredragande för centrumet ligger hos föreståndare och vice föreståndare.

CCGEx styrelse har under perioden (med byte av VCCrepresentant under perioden) av:

Tommy Björkqvist	SICEC, Ordförande
Björn Birgisson	KTH
Gunilla Efraimsson	KTH
Per Lange	Scania CV
Annika Kristoffersson (2011-2012) / Lucien Koopmans (2013)	Volvo Cars
Johan Wallesten	Volvo GTT
Anders Johansson	Energimyndigheten

Tabell 1 CCGEx styrelse

CCGEx är ett forskningssamarbete mellan industri och högskola, där högskolan är huvudsaklig forskningsutförare. Högskoledelen av CCGEx är organiserad kring en centrumledningsgrupp, Figur 2, vilken har i uppdrag att utarbeta och förvalta centrumets forskningsinriktning/forskningsområden och vision/syfte/mål.



Figur 2 CCGEx ledningsstruktur högskola

CCGEx centrumledningsgrupp har under perioden 2012/2013 bestått av:

Jonas Holmborn	Föreståndare, ITM
Mats Åbom	Vice föreståndare, SCI
Andreas Cronhjort	Förbr.motor, ITM
Niklas Winkler (2012)	Förbr.motor, ITM
Mihai Mihaescu	Fluidmekanik sim, SCI
Nils Tillmarkt	Turbolab Fluidmekanik exp, SCI
Ramis Örlü	Fluidmekanik exp, SCI
Hans Boden (2012)	MWL, SCI
Susann Boij (2013)	MWL, SCI

Tabell 2 CCGEx centrumledningsgrupp

Remissinstanser för centrumledningen består av centrumets refensgrupp, Tabell 3, där industri- och akademirepresentanter möts, samt CCGEx vetenskapligaråd, Tabell 4.

CCGEx industrirepresentation i referensgruppen har bestått av:

Per-Inge Larsson	Scania CV
Daniel Norling	Scania CV
Eric Baudion	Scania CV
Dennis Konstanzer	Scania CV
Elias Johansson	Volvo GTT
Magnus Ising	Volvo GTT
Johan Lennblad	Volvo Cars
Magnus Knutsson	Volvo Cars

Tabell 3 Industrirepresentation referensgrupp

CCGEx vetenskapliga råd har bestått av:

Jonas Holmborn	Föreståndare, ITM
Mats Åbom	Vice föreståndare/professor, MWL SCI
Hans-Erik Ångström	Professor, förb.motor ITM
Andreas Cronhjort	Docent,förb.motor ITM
Henrik Alfredsson	Professor, fl.mech SCI
Laszlo Fuchs	Professor, fl.mech SCI

Tabell 4 Vetenskapligt råd

Huvudresultat

Under året, och i samband med den nya föreståndarens tillträde, har ett arbete kring centrumets organisation startas och till stor del implementerats.

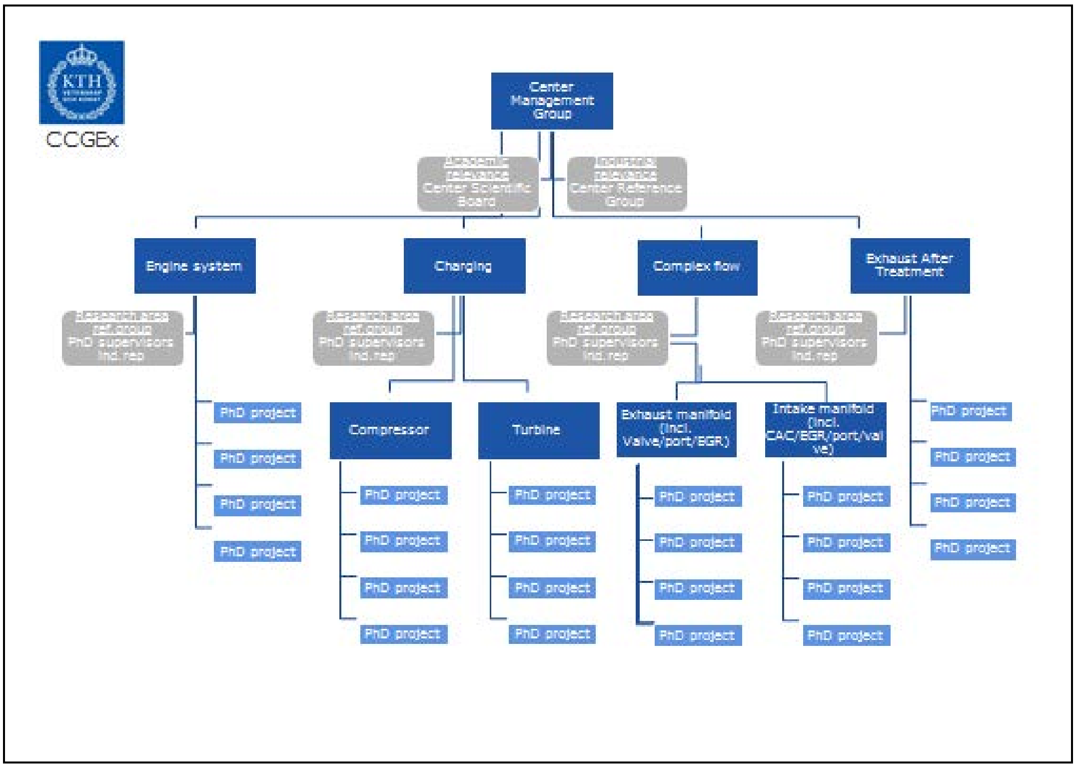
Grundtanken i organisationen är att identifiera forskningsområden vilka stämmer med centrumets vision/strategi, industrins behov och deltagande parters kompetenser och resurser.

Utgångspunkten för formuleringen av forskningsområden har varit industrins road map, vilket innehåller framtida utmaningar, intresseområden och tekniker som den tunga (Scania och Volvo GTT) respektive lätta (Volvo GTT och fd SAAB) sidan har sammanställt inom SICEC samarbetet. Från dessa har områden som ”motorsystem”, ”överladdning”, ”komplexa flöden” och ”avgasbehandling” identifierats.

För dessa områden formuleras forskningsfrågor i samröre mellan akademin och industrins representanter inom respektive forskningsområdes referensgrupp. Syftet med att formera referensgrupper kopplat till respektive forskningsområde är att öka kontakten, informationsutbytet och samplaneringen mellan centrumets högskoleparter samt industrin.

Organisationen och arbetssättet har som först implementerats på formuleringen av forskningsområdet ”compressor off design – surge”.

Organisationen visualiseras i Figur 3



Figur 3 Forskningsorganisation CCGEx

Leveranser från centrumet består av ökad förståelse och ny kunskap kring gasväxlingssystem i allmänhet och överladdning/turbo i synnerhet. Förståelsen sprids genom ett antal kanaler där möten och diskussioner med ingenjörer i industrin och publikationer är några exempel. Under perioden (2011-2013) har 49 kvalitetsgranskade publikationer gjorts i centrumets namn, se Bilaga 3 Publikationslista för komplett lista. De mest tydliga leveranserna är dock de examina, doktor/licenciat/MSc som avläggs inom eller i nära samarbete med CCGEx.

Examina

Under aktuell programperiod har examina i form av doktorsexamen, licenciatexamen samt Master of Science examen avlagts inom CCGEx verksamhetsområden som sträcker sig från grundläggande kunskap inom experimentellkaraktärisering av grundläggande strömningsstrukturer i rörsystem till kompressor och turbin, flödesmätning av pulserande strömning samt mätmetoder för beröringsfri tryckmätning i rör och roterandekomponenter. Vidare experimentella arbeten har presenterats och försvarats inom akustisk karaktärisering av turboaggregat, kanalströmning och ljuddämpande principer och lösningar för gasväxlingssystem. Simuleringskunskap och studier är viktiga komponenter för CCGEx kompetens och leveranser till sina partners. Inom detta område har avhandlingar gällande full 3D strömingssimulering samt 1D gasdynamiksimulering applicerats på gasväxlingssystem som avgasventil/port, avgassamlare, turbin, EGRsystem och motorn som helhet i såväl stabil som transient drift.

Totalt har 7 doktorandavhandlingar, 8 licenciatavhandlingar och 13 Master of Science arbeten presenterats, för vidare detaljer kring titel och person se Bilaga 2 Examina.

Disputerade personer har gått vidare till anställningar inom akademin både i sverige och i utlandet, vissa till fordonstillverkare som är partners i CCGEx men den största arbetsgivaren för CCGEx disputerade är konsultbolag inom fordonsbranschen. Ett stickprov i januari 2014 indikerar att så många som fyra från CCGEx disputerade personer har uppdrag enbart på Scania.

Måluppfyllelse

Måluppfyllensen var en av de punkter som adresserades vid den utvärdering som Faugert & CO utförde under våren 2013. I samband med denna gjordes en intern egenutvärdering i kombination med en extern exertutvärden av vetenskapliga parameterar (expert utvärdering av vetenskaplig produktion) samt av organisation och kommunikation (Faguert & CO). Den samlade bilden är att CCGEx hittills har uppfyllt sitt övergripande syfte väl och bör bedömas ha goda förutsättningar att fortsätta att göra det. Även när det gäller de mera specifika målen för programperioden och de angivna framgångskriterierna är bilden positiv från såväl externa experter som den interna uppfattningen.

Specifika mål och kriterier och kommentarer kring dem presenteras i Bilaga 1 Specifik måluppfyllese samt kommentarer

Effekter i samhället

Det tar ofta mycket lång tid för resultat och effekter av forskningsprojekt att bli observerbara, speciellt som arbetet inom kompetenscentrum bedrivs med deltagande av industrier som samtidigt är konkurrenter, vilket driver projekten till att vara av generisk och ej av produktnära karaktär. De effekter som CCGEx kan tänkas ha på samhället tar av naturliga skäl mer än ett par år att uppstå och det finns än inga exempel på iakttagna effekter.

Effekter som CCGEx kan tänkas ha framöver diskuteras inom programbeskrivningen där CCGEx förväntas spela en viktig roll beträffande minskad bränsleförbrukning och de lagkrav som finns på begränsningen av emissioner. Lagkraven innebär ett ökat beroende av efterbehandlingssystem utan att öka bränsleförbrukningen, vilket är frågeställningar som ligger inom centrumets område. På den tunga sidan kan energibesparing uppnås genom vidareutveckling av förbränningsmotorn vilket kommer att bidra till energieffektivisering.

Dessa lagkrav, i kombination med den hårda internationella konkurrensen, innebär höga kostnader för företagen. Då flera av de deltagande svenska företagen är delar av internationella företag kommer de troligtvis bli utsatta för påtryckningar om förflyttning och sammanslagning, och stark konkurrenskraft blir då ett sätt att behålla dem i Sverige. Att ett kompetenscentrum, i detta fall CCGEx, kan hjälpa att säkerställa industrins framtida konkurrenskraft innebär därmed en indirekt nytta för samhället i stort. Inom CCGEx bedrivs också verksamhet kopplad till minskat buller från minskat buller från biltrafik via kunskapsbyggandet kring ljudalstring, transferering och dämpning i motorkomponenter och system.

Genomförande

CCGEx forskning under perioden har omfattat system, komponenter samt grundläggande fysikaliska strukturer som pulserande strömning i rör. Ambitionen under perioden har varit att gå ifrån ett upplägg där många områden täcks med enstaka aktiviteter/studenter till att begränsa antalet forskningsområden, ambitionen är cirka tre stycken, för att i de områden där CCGEx är aktiva kunna lägga mer resurs. Genom fokuseringen kan de aktuella frågeställningarna belysas och utredas från ett antal olika perspektiv genom de olika kompetenser och discipliner som är knutna till CCGEx på KTH. Relevanta fokusområden har tagits fram baserat på industrins road-map/utmaningar och diskussioner på centrum möten då industrins aktuella prioriteringar har lyfts fram. Formulering av forskningsfrågor samt forskningsupplägg har bedrivits inom KTH med en områdesansvarig från ledningsgruppen som sammanhållande för beredningen.

CCGEx har, på samma sätt som de andra centrumen inom SICEC, kontinuerligt tagit in synpunkter via årliga besök av en International Advisory Board (IAB).
Vidare har CCGEx tillsammans med övriga kompetenscentrum inom förbränningsmotorteknik utvärderats under våren 2013, vilket utfördes av den av Energimyndigheten anlitad konsultfirman Faugert&CO.

I utvärderingsrapportens vetenskapliga bedömning av verksamheten konstateras att ”den övergripande bedömningen av kompetenscentrumet CCGEx är tydligt positiv och forskningsaktiviteterna bedöms som relevanta och internationellt konkurrenskraftiga”.

Vid periodens början var ett antal projekt uppstartade inom ramen för det tidigare CICEROcentrumet. Under periodens senare del har det stora antalet områden ersatts med fokusering inom ett begränsat antal områden men med större resurs från flera discipliner inom samma frågeställning. I och med denna strategiomläggning och en osäkerhet gällande finansieringen då SAAB försvann under perioden har inte de avslutade doktorandprojekten ersatts direkt med nya i samma takt. Under 2012 startades ett första gemensamt område kallat ”compressor off design operation” upp där resurser från alla discipliner arbetar inom samma frågeställning. I Figur 4 visas forskningsområden, projekt och deras tidsfasning inom perioden rapportens tidsperiod. Projektens tidsutsträckning har dragits utanför 2011-2013 för att ge överblick över projektens fasning.

För detaljerad beskrivning av forskningsformulering, analys och resultat för respektive projekt hänvisas till Bilaga 4 Projektposters och Bilaga 3 Publikationslista.

Inom motorsystem har projekt för att möjliggöra hantering av transienta förlopp i motorsimulering bedrivits inom ”study of turbo chargers on engine”. Här analyserades värmeöverföring i turboaggretat för att kunna modellera värmeflöde i turbo och applicera detta i 1D modelleringsverktyg.

Restvärme återvinning i motorsystem har studierats simuleringsmässigt inom ”Waste Heat Recovery”. Studier av idealiserade komponenter för användning av turbocompound har genomförts för att identifiera dimensionerande system och komponenter vid användning av turbocompoundturbiner och möjliga sätt att undvika begränsande fenomen.

Inom ”Improved use of blow down energy” har ett koncept för att begränsa pumparbetet vid gasväxlingen i kolvmaskinen i kombination med turboaggregat undersökts och utvärderats för möjliga applikationer i lätt och tungapplikation.

För turbon som isolerat system har verktyg och metoder för att karaktärisera akustiska egenskaper hos turboaggregat i rigg utvecklats inom ”Experimental characterisation of turbo chargers” och ”CFD modelling of turbo charger acoustics”

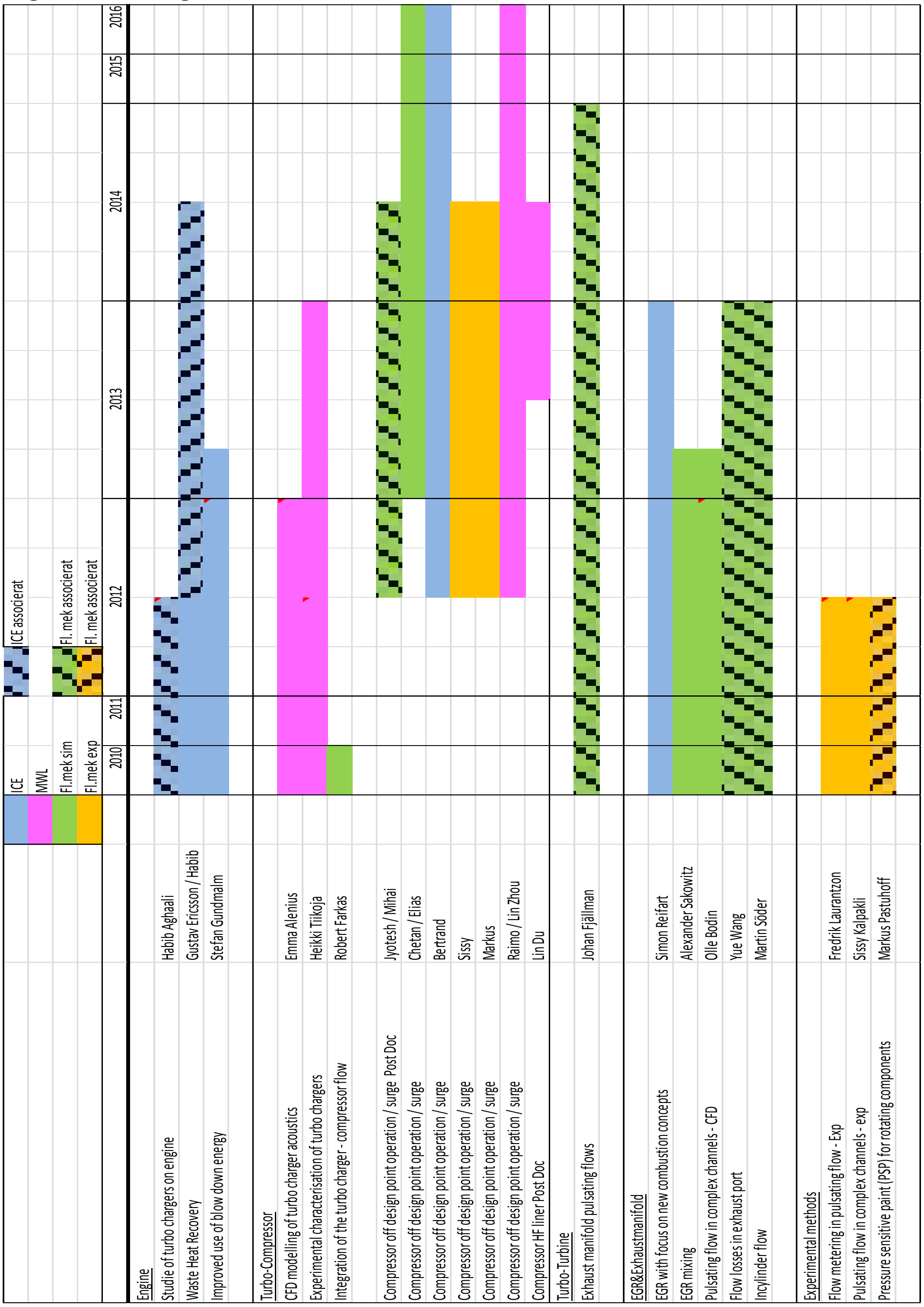
I och med uppstart av nya forskningsområden under 2012 formulerades området ”compressor off design operation – surge”. Här har karaktärisering av turboakustik nära och under surge genomförts experimentellt i CICEROlabbet samt i parallell har strömningssimuleringar genomförts för att först verifiera CFDverktyg och metod vilka nu övergått till analys av hur och var störningar vilka utvecklas till surge uppstår.

Inom turbinområdet har studier av strömingsstrukturer i kollektor och genom turbin genomförts i form av CFDstudier inom ”exhaust manifold pulsating flows”

Systemstudier kring EGRkonfigurationer och dess prestanda drivande parameterar har bedrivits inom ”EGR with focus on new combustion concepts” där förbränningsmotordoktoranden också samarbetat med simuleringsdoktoranden inom ”EGR mixing”. Detaljstudier av vilka strömningsstrukturer och fenomen som driver tryckfall och strömningsfält i avgasventil, port och avgassamlare har bedrivits inom ”pulsating flow in complex geometries”, ”flow losses in exhaust port” och ”incylinder flow”.

Samtidiga studier av strömningsfenomen och metodutveckling av mätmetoder för massflödesmätning av pulserandeströming (”flow metering in pulsating flow”), icke störande mätning av tryck (”pressure sensitive paint for rotating components”) och applicering av multikomponent PIV i stationär/pulserande strömning (”pulsating flow in complex channels”).

Under 2013 startades, i linje med den strategiskaplanen, ett andra fokusområde upp – heta sidan – där system, komponenter och fenomen på motorns heta avgassida interagerar och modelleras.



Figur 4 Forskningsområden & projekt inom aktuell finansieringsperiod (ICE-förbränningsmotorteknikenheten, MWL-akustikenheten, FL.mek-mekanikinst.)

Ekonomisammanställning

Ekonomin för det 2010 omstartade kompetenscentrumet har under delar av aktuell period varit utmanad då en av fyra industriella partner (SAAB) under 2010 hamnade på ekonomiskt obestånd och slutligen 2011 gick i konkurs. Detta gjorde att en fjärdedel av budgeterad intäkt från industrin försvann redan i ett tidigt skede av perioden. Frånfallet av SAAB har under aktuell period kompenserats av att kvarvarande industriella parter har ökat sin insats genom skjuta till ytterligare in-kind utöver den initialt planerade.

KTH har ökat sin insats genom att låta ett antal stipendiater från Chinese Science Counscil (CSC) samt EU knytas till centrumet vilket ytterligare ökat resurs till centrumet.

Detaljerad ekonomiuppföljning med nedbrytning på områdesnivå sker i separat ekonomirapportering. En mycket kort sammanfattning på övergripandenivå ges i Tabell 5

KTH kontant		2907996
KTH inkind		22561000
KTH direkt		**25468996**
KTH EU+CSC		*7800000*
KTH totalt		*33268996*
Industri kontant		5400000
industri inkind		16721325
Totalt industristöd		**22121325**
Energimyndigheten		**21000000**

Tabell 5 CCGEx ekonomisummering för perioden 2011-2013

CCGEx har alltså totalt, inkluderande både kontant och in-kind insatser, omsatt 76 MSek med en bidragsnivå från energimyndigheten på 31%, industri 32% och KTH37%.

Bilaga 1 Specifik måluppfyllese samt kommentarer

<table>
<tr><td>Mål:</td><td>Kommentar</td></tr>
<tr><td>att utveckling av experimentell teknik och mätmetodik relevanta för gasväxling har pågått och använts i olika projekt</td><td>Exempel:
EGR mätning mha CO2 sampling, fast-soot-sensor, diodlaser absorption

massflödesmätning i pulserande flöde, vortex shedding meter användning av wavelet teknik

unik rig för bestämning av akustiska 2-portsdata inkl ljudalstring för turbo-aggregat

PIV-mätningar i grenrörsliknande geometrier

Tryckkänslig färg (PSP) för instationära tryckmätningar i pulserande strömning i grenrörsliknande geometrier</td></tr>
<tr><td>avancerade numeriska modeller (CFD-LES) har applicerats för detaljerade studier inom området</td><td>Simulering och utvärdering av dominerande strukturer i strömning mha DMD och POD analys. Utvärdering av tryckfalls drivande strukturer i avgasventil/port/grenrör Analys och jämförelse mellan detaljerad (tid och rymd) LES och industri RANs i grenrör/turbin

Simulering av blandning och fördelning av EGR i inloppsrör. Utvärdering av blandningsprocess samt jämförelse med 1D simulering och experimentella data</td></tr>
<tr><td>att numeriska modeller har verifierats med avancerad experimentell teknik</td><td>EGR blandning/fördelning i inloppsrör, kopplade undersökningar genom LES simuleringar ⇔1D GTPower ⇔ experimentella data</td></tr>
<tr><td>att i genomsnitt 2 licentiat- och doktorsexamina/år1</td><td><table><tr><td>2011</td><td>2012</td><td>2013</td></tr><tr><td>2 PhD</td><td>2 PhD</td><td>3 PhD</td></tr><tr><td>2 Lic</td><td>4 Lic</td><td>3 Lic</td></tr></table></td></tr>
</table>

<table>
<tr><td>att CCGEx är representerat vid relevanta konferenser så att minst 10 vetenskapliga artiklar och konferenspresentationer per år med CCGEx:s signum har publicerats har avlagts</td><td><table><tr><td>2011</td><td>2012</td><td>2013</td></tr><tr><td>15st</td><td>15st</td><td>2st</td></tr></table></td></tr>
<tr><td>att i genomsnitt en artikel/år publiceras med en utomlands baserad forskare</td><td>Då vi har samarbeten i form av EU projekt har vi studenter som är delvis placerade på KTH och delvis på ex Tallin och Kairo univ. LES har publicerats med Larmi SF. En artikel (PSP) tillsammans med forskare i Japan är inskickad i reviderad version.</td></tr>
<tr><td>att i genomsnitt en doktorand/år inom CCGEx har forskat vid utländskt universitet eller forskningsenhet</td><td>Under 2012 så forskade Pastuhoff tre månader vid Tohoku University, Sendai, Japan och Kalpakli tre månader vid Princeton University, USA.</td></tr>
<tr><td>att ge minst två doktorandkurser inom området per år</td><td>Compressible flows (Henrik Alfredsson)
Aeroacoustics (Mats Åbom)

Signal Analysis (Hans Bodén)

Compressor flows (Mihai Mihaescu)

Uncertainty analysis (Henrik Alfredsson)</td></tr>
<tr><td>att stärka avdelningen Förbränningsmotorteknik genom tillsättning av åtminstone två akademiska tjänster</td><td>Lektor (Andreas Cronhjort)
Rekrytering ny professor i Förbrän-ningsmotorteknik pågår, tjänsteförslagsnämnd har levererat rekommendation till rektor jan 2014</td></tr>
<tr><td>öka antalet seniora forskare verksamma inom CCGEx</td><td>Följande post-doktor är anställda under perioden och har del av sin verksamhet knuten till CCGEx: Niklas Winkler, Mihai Mihaescu, Andreas Holmberg, Lin Du, Susann Boij</td></tr>
<tr><td>att öka antalet industriella partner engagerade i CCGExs forskning med minst två under programperioden</td><td>Samarbeten inom delområden med VTT och Wärtsilä (Finland)
Swenox</td></tr>
</table>

	Honeywell
att öka finansiering via direkta medel inkluderande associerade projekt till minst 20 milj SEK/år	Summering av kontant+in-kind blir 23-24 MSek per år 2011-2013
att etablera åtminstone en adjungerad professor eller lektor från industrin verksam inom CCGEx	Föreståndaren har rekryterats och är betald av industrin. Andreas Cronhjort (tidigare arbetsgivare Scania) har anställts som lektor vid KTH.
att bli koordinator eller deltagare i åtminstone ett EU-finansierat projekt	Deltar i 1 EUprojekt (MWL 1) Koordinerar ansökan till GAME-NET
CCGEx skall bidra till att fler kvinnor rekryteras som examensarbetare, forskarstuderande och till tjänster på högre akademisk nivå för att möjliggöra en jämnare fördelning mellan män och kvinnor inom universitet och företag.	En kvinnlig doktorand är för närvarande verksam (planerad disputation Q2 2014), en har disputerat 2012, en har avslutat med TeknL och en kvinnlig examensarbe-tare har examinerats inom CCGEx

Bilaga 2 Examina

Bodin, O. (2013) *Simulations of compressible flows associated with internal combustion engines.* PhD thesis, KTH Mechanics

Sakowitz, A. (2013) *Computation and analysis of EGR mixing in Internal Combustion Engines.* PhD thesis, KTH Mechanics

Wang, Y. (2013) *Numerical Studies of Flow and Associated Losses in the Exhaust Port of a Diesel Engine*. PhD thesis, KTH Mechanics

Gundmalm, S. (2013) *Divided Exhaust Period on Heavy-Duty Diesel Engines.* Licentiate thesis, KTH Internal Combustion Engines

Fjällman, J. (2013) *Unsteady simulations of the turbulent flow in the exhaust system of an IC-engine for optimal energy utilization.* Licentiate thesis, KTH Mechanics,

Le Bihan, T. (2013) *Accuracy of PSA's DPF soot load estimator calibrated by means of a DoE model*, MSc thesis,

Sjöberg E. (2013) *Friction Characterization of Turbocharger Bearings*, MSc thesis, KTH Internal Combustion Engines

Alenius, E. (2012) *Flow Duct Acoustics: An LES Approach*. PhD thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Laurantzon, F. (2012) Flow measurements related to gas exchange applications. PhD thesis, KTH Mechanics

Aghaali, H. (2012) *On-Engine Turbocharger Performance Considering Heat Transfer.* Licentiate thesis, KTH Internal Combustion Engines

Elsaadany, S. (2012) *Investigation and Optimization of the Acoustic Performance of Exhaust Systems*. Licentiate thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Kalpakli, A. (2012) *Experimental study of turbulent flows through pipe bends.* Licentiate thesis, KTH Mechanics

Tiikoja, H. (2012) *Acoustic Characterization of Turbochargers and Pipe Terminations*. Licentiate thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Ferro, M. (2012) *Experimental study on turbulent pipe flow*, MSc thesis

Qazizadeh, A. (2012) *Analytical and Numerical Analysis of the Acoustics of Shallow Flow Reversal Chambers*, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Svanberg, P. (2012) *Analysis and design of a semi-active muffler*, MSc thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Vernet, J. (2012) Detailed study of steady incylinder flow and turbulence using stereo-PIV, MSc thesis, KTH Mechanics

Westlund, A. (2011) *Simplified models for emission formation in diesel engines during transient operation*. PhD thesis, KTH Internal Combustion Engines

Winkler, N. (2011). *Reduced models for flows in IC-engines*. PhD thesis, KTH Internal Combustion Engines

Ottosson, T. and **Holmberg, S.** (2011) *Free Valves: The Effect of Different Valve Strategies on In-Cylinder Flow, Emissions and Performance in a Heavy Duty Diesel Engine.* MSc thesis, KTH Internal Combustion Engines

Pimenov, D. (2011) *Investigation og Nonlinear Acoustical Properties of Perforated Plate Samples and Samples of Aircraft Engine Liners*, MSc thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Sattarzadeh, S.S. (2011) *Experimental study of complex pipe flow.* MSc thesis, KTH Mechanics

Sedarati, P. (2011) *Simulations of sound propagation at a duct termination with flow*, MSc thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Weng, C. (2011) *Comparison of perforate impedance models*, MSc thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Zhenrui, W. (2011) *Sound generation from turbo-compressors*, MSc thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Zu, X. (2011) *Acoustics of parallel baffles muffler with Micro-perforated panels*, MSc thesis, KTH The Marcus Wallenberg Laboratory for Sound and Vibration Research

Bilaga 3 Publikationslista

Journal & Conference Papers

2013

Åbom, M. and **Allam, S.** (2013) *Dissipative Silencers Based on Micro-Perforated Plates.* SAE Technical paper 2013-24-0071. dx.doi.org/10.4271/2013-24-0071

Aghaali, H. and **Ångström, H.E.** (2013) *Temperature Estimation of Turbocharger Working Fluids and Walls under Different Engine Loads and Heat Transfer Conditions*. SAE/11th International Conference on Engines & Vehicles, 2013-24-0123. dx.doi.org/10.4271/2013-24-0123

Aghaali, H. and **Ångström, H.E.** (2013) *Demonstration of Air-Fuel Ratio Role in One-Stage Turbocompound Diesel Engines.* SAE/KSAE 2013 International Powertrains, Fuels & Lubricants Meeting, 2013-01-2703. papers.sae.org/2013-01-2703/

Allam, S. and **Åbom, M.** (2013) *Whistling Potential for Duct Components*. SAE Technical paper 2013-01-1889. dx.doi.org/10.4271/2013-01-1889

Bodin O., **Wang Y.**, **Mihaescu M.**, and **Fuchs L.** (2013). *LES of the Exhaust Flow in a Heavy-Duty Engine.* Oil Gas Sci. Technol. – Rev. IFP Energies nouvelles. dx.doi.org/10.2516/ogst/2013117

Gundmalm, S., Cronhjort, A. and **Ångstrom, H.E.** (2013) *Divided Exhaust Period: Effects of Changing the Relation between Intake, Blow-Down and Scavenging Valve Area.* SAE 2013, 2013-01-0578. dx.doi.org/10.4271/2013-01-0578

Jyothishkumar, V., **Mihaescu, M.**, **Semlitsch, B.**, and **Fuchs, L.**, (2013) *Numerical Flow Analysis in a Centrifugal Compressor near Surge Condition.* AIAA Paper, AIAA 2013-2730. dx.doi.org/10.2514/6.2013-2730

Kabral, R., **Rämmal, H.** and **Åbom, M.** (2013) *Acoustical Methods for Investigating Turbocharger Surge*. SAE Technical paper 13NVC-0075. dx.doi.org/10.4271/2013-01-1879

Kalpakli, A. and **Örlü, R.** (2013) *Turbulent pipe flow downstream a 90° pipe bend with and without superimposed swirl.* Int. J. Heat Fluid Flow. **41**:103–111. dx.doi.org/10.1016/j.ijheatfluidflow.2013.01.003

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Sattarzadeh, S.S., Kalpakli, A., and **Örlü, R.** (2013) *Hot-Wire Calibration at Low Velocities: Revisiting the Vortex Shedding Method.* Advances in Mechanical Engineering. **2013**:241726. dx.doi.org/10.1155/2013/241726

Sakowitz A., **Mihaescu M.**, and **Fuchs L.** (2013). *Turbulent Flow Mechanisms in Mixing T-junctions by Large Eddy Simulations.* Int. J. Heat Fluid Flow, **45**:135–146. dx.doi.org/10.1016/j.ijheatfluidflow.2013.06.014

Sakowitz A., **Mihaescu M.**, and **Fuchs L.** (2013). *Flow Decomposition Methods applied to the Flow in an Internal Combustion Engine manifold. Appl. Therm. Eng.*, **65**:57–65. dx.doi.org/10.1016/j.applthermaleng.2013.12.082

Sakowitz, A., **Mihaescu, M.** and **Fuchs, L.** (2013) *Effects of velocity ratio and inflow pulsations on the flow in a T-junction by Large Eddy Simulation*. Comput. Fluids. **88**:374–385. dx.doi.org/10.1016/j.compfluid.2013.10.001

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Semlitsch, B., **Jyothishkumar, V.**, **Mihaescu, M.**, **Fuchs L.**, and **Gutmark, E. J.** (2013) *Investigation of the Surge Phenomena in a Centrifugal Compressor Using Large Eddy Simulation.* ASME Paper, IMECE2013-66301.

Wang, Y., **Semlitsch, B.**, **Mihaescu, M.**, and **Fuchs, L.** (2013) *Flow Structures and Loses in the Exhaust Port of an Internal Combustion Engine.* ASME Paper, IMECE2013-64610.

Zhou, L. and **Bodén, H.** (2013) *The effect of combined high level acoustic excitation and bias flow on the acoustic properties of an in-duct orifice.* 19th AIAA/CEAS Aeroacoustics Conference. AIAA 2013-2128. dx.doi.org/10.2514/6.2013-2128

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Aghaali, H. and **Ångström, H.E.** (2012) *Turbocharged SI-Engine Simulation with Cold and Hot-Measured Turbocharger Performance Maps*. ASME Turbo Expo 2012, GT2012-68758. abstract.

Aghaali, H. and **Ångström, H.E.** (2012) *Improving Turbocharged Engine Simulation by Including Heat Transfer in the Turbocharger.* SAE 2012, 2012-01-0703, dx.doi.org/10.4271/2012-01-0703.

Alenius, E., **Åbom, M.** and **Fuchs, L.** (2012) *LES of Acoustic-Flow Interaction at an Orifice Plate.* 18th AIAA-CEAS Aeroacoustics conference. AIAA Paper 2012-2064, dx.doi.org/10.2514/6.2012-2064.

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Kierkegaard, A., **Allam, S.**, **Efraimsson, G.** and **Åbom, M.** (2012) *Simulations of whistling and the whistling potentiality of an in-duct orifice with linear aeroacoustics.* J. Sound Vibration, **331**:1084–1096. dx.doi.org/10.1016/j.jsv.2011.10.028

Laurantzon, F., **Tillmark, N.**, **Örlü, R.** and **Alfredsson, P.H.** (2012) *A flow facility for the characterization of pulsatile flows*. Flow Meas. Instrum. **26**:10–17. dx.doi.org/10.1016/j.flowmeasinst.2012.04.009

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Elnady, T., **Elsaadany, S.** and **Åbom, M.** (2011) *Flow and pressure drop calculation using two-ports*. J. Vib. Acoust., **133**:04106. dx.doi.org/10.1115/1.4003593

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Holmberg, A., **Åbom, M.** and **Bodén, H.** (2011) *Accurate experimental two-port analysis of flow generated sound*. J. Sound Vibration, **330**:6336–6354. dx.doi.org/10.1016/j.jsv.2011.07.041

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Pastuhoff, M. (2011) *Experimental evaluation of polymer/ceramic pressure sensitive paint by measuring wall pressure in a y-junction at pulsating flow*. In Svenska Mekanikdagar, Chalmers Göteborg, Sweden.

Pastuhoff, M., **Tillmark, N.** and **Alfredsson, P.H.** (2011) *Wall pressure measurements in a y-junction at pulsating flow using polymer/ceramic pressure sensitive paint*. In Proc. 10th Int. Symp. Exp. Comp. Aerothermodynamics of Internal Flows, Brussels, Belgium. abstract, pdf

Sakowitz, A. and **Fuchs, L.** (2011) *Computation of mixing processes related to EGR*. Proc. 7th Int. Turbulence Shear Flow Phenomena (TSFP-7). pdf

Sakowitz, A. and **Fuchs, L.** (2011) *LES of the turbulent mixing process in a T-junction with stationary and pulsating inflow conditions.* Proc. 10th Int. Symp. Experimental Computational Aerothermodynamics of Internal Flows.

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Technical reports

2011

S. Gundmalm. *Divided exhaust period improved use of blow down energy*. Technical report, 2011.

Bilaga 4 Projekt "posters"

On-Engine Turbocharger Performance

KTH CCGEx

Habib Aghaali

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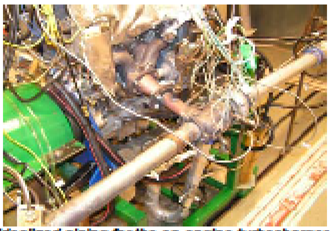
Abstract

Engine simulation based on one-dimensional gas dynamics is well suited for integration of all aspects arising in engine and power-train developments. Commonly used turbocharger performance maps in engine simulation are measured in non-pulsating flow and without taking into account the heat transfer. However, on-engine turbochargers are exposed to pulsating flow and varying heat transfer situations. The aim of this project is to improve the quality of simulation of a turbocharged engine by considering heat transfer in the turbocharger. A set of experiment has been designed and performed on a water-oil-cooled turbocharger, which was installed on a 2 liter GDI engine with variable valve timing, for different load points of the engine and different conditions of heat transfer in the turbocharger. The experiments were the base to simulate heat transfer on the turbocharger, by adding a heat sink before the turbine and a heat source after the compressor. The result from the measurement are intended to improve simulations through better understanding of the performance maps from the manufactures and how to judge and adjust them in view of real engine non-ideal assemblies.

Background

High exhaust temperature causes significant amount of heat transfer in an automotive turbocharger; however, this heat transfer is rarely measured or accounted for in any turbocharger performance or turbocharged engine simulation. The project aims to determine: heat transfer in the turbocharger, a heat transfer model for the on-engine turbocharger, and GT-POWER model of the turbocharged engine.



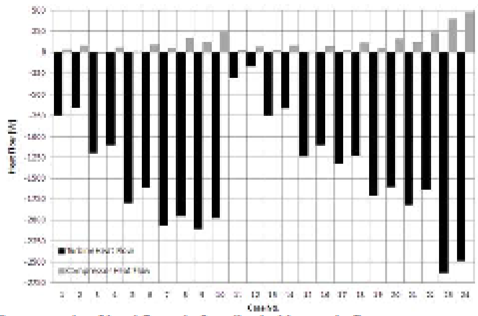
Idealized piping for the on-engine turbocharger.

Instrumented turbocharger installed on the engine

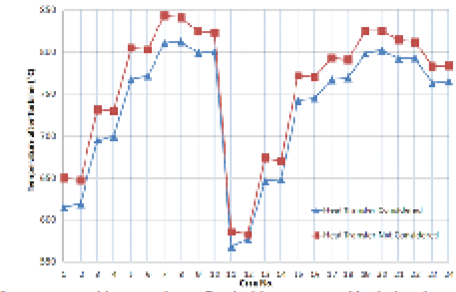
Method

1. Experimental investigation of turbocharged engine in different heat transfer situations of the turbocharger.
2. Simulation of turbocharged engine by considering heat transfer of the turbocharger and tuning against the measurement.
3. Theoretical investigation of heat transfer of the turbocharger. A heat transfer model based on the theory has been made to be in agreement with the different heat transfer conditions on the turbocharger.
4. Combining simulation and modeling and then verifying by the experiment.

Results



The amounts of heat flows before the turbine and after compressor for different engine load points.



Mass averaged temperature after turbine vs. case No. in two types of simulation; First heat transfer in the turbocharger is considered which is exactly as same as the measurement, and second heat transfer in the turbocharger is not considered.

Conclusions

A combined measurement and simulation of a turbocharged engine has been done, in order to study heat transfer in the turbocharger and improve engine simulation precision and predictability. The study has shown that heat transfer in the turbocharger is very crucial to take into account in engine simulations, and it improves simulation predictability.

KTH CCGEx

Waste Heat Recovery Turbocompound

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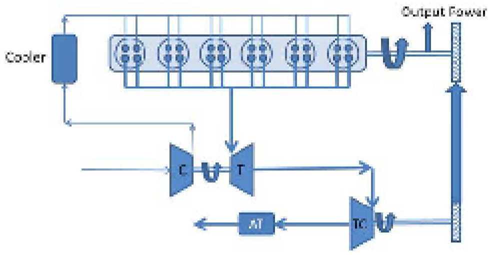
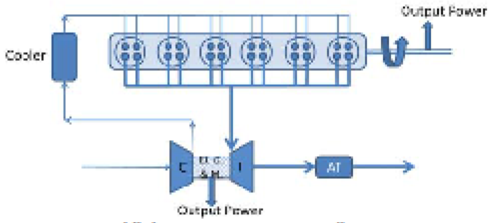
Abstract

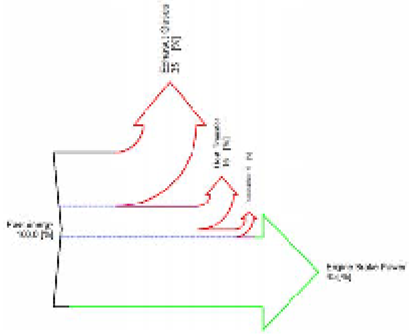
Theoretically show the potential of turbocompound as a Waste Heat Recovery (WHR) system on internal combustion engines in combination of advanced technologies.



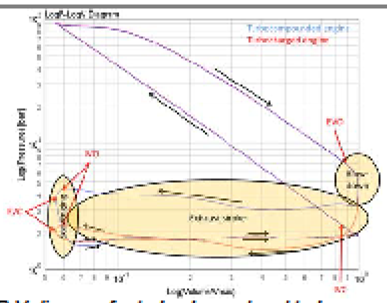
Low-pressure compounding.



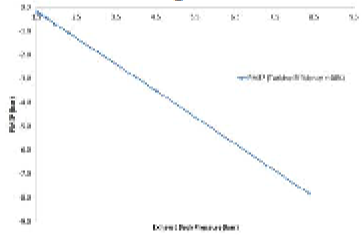
High-pressure compounding.



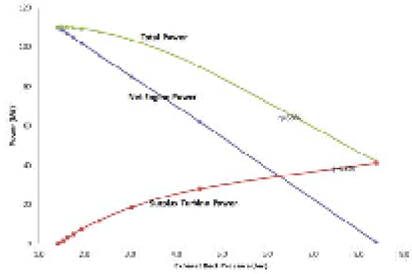
Diesel engine performance for a low engine speed and medium load.



Log P-V diagram for turbocharged and turbocompound engine.



Pumping work vs. Exhaust back pressure for a low engine speed and medium load.



Trade-off between turbine power and engine power for a low engine speed and medium load.

Divided Exhaust Period

Improved use of blow-down energy

KTH CCGEx

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Abstract

It is becoming increasingly important to reduce the fuel consumption of vehicles both from an environmental point of view and for the sake of end consumer's fuel economy. Engine performance has been improved over the years by means of many different research areas, where one of these are the use of free valve technology. In this project, a gas exchange concept called Divided Exhaust Period (DEP) that utilizes free valve technology will be numerically simulated on a variety of engine types. The aim is to reduce fuel consumption, residual gas content and improve transient response while maintaining current EGR (Exhaust Gas Recirculation) rates.

Background

Introducing a turbocharger on an engine creates an exhaust back pressure for the piston to work against during the exhaust stroke. As a way to reduce these pumping losses a second exhaust manifold is introduced, that leads the exhaust gases past the turbine. The standard two exhaust valves are each assigned to one of the two manifolds, as can be seen in Figure 1. The valves and manifold connected to the turbine are denoted as the blow-down system, while the valves and manifold that are bypassing the turbine are denoted as the scavenging system. The strategy of the Divided Exhaust Period (DEP) concept is to let the initial high enthalpy blow-down pulse run the turbine, but lead the exhaust gases through the scavenging system during the rest of the exhaust stroke. Since the piston then can expel the exhaust gas out of the cylinder against atmospheric pressure instead of the turbine back pressure, a reduction in pumping losses is achieved. This in turn leads to a potential reduction in fuel consumption.

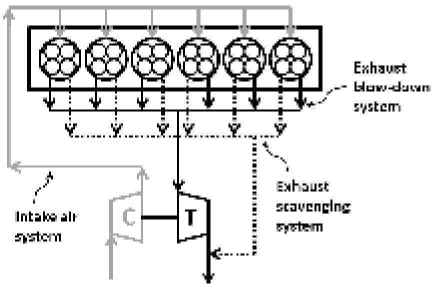

Fig. 1 Engine sketch of the DEP concept.

Method

The DEP concept will be initially investigated through extensive numerical simulations with the aid of GT-Power, which is a 1D code for engine simulations. Baseline models for the different engines that are under investigation are calibrated against measurement data acquired at the engine test cell facilities of KTH. These baseline models are then modified to incorporate the DEP concept and simulations covering optimization of valve timing strategies, valve sizes, turbocharger matching etc. is carried out, and results are compared to the baseline models. If the numerical simulations show potential improvements, the project can be extended to incorporate real engine tests with a prototype DEP engine.

Results

Fig. 2-3 shows results of DEP simulation on a Scania Euro3 HD-Diesel engine running at 1400 rpm and 1200 Nm.

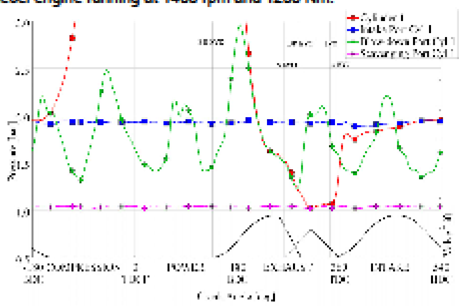

Fig. 2 Pressure in cylinder, intake port, blow-down port and scavenging port.

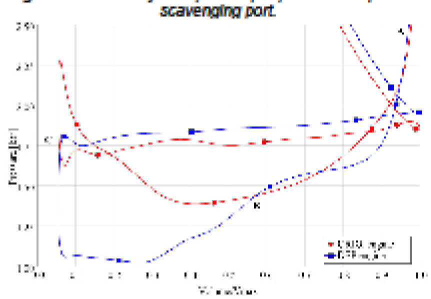

Fig. 3 Pressure vs. volume for the original and the DEP engine during the gas exchange loop for the same load point as above.

Conclusions

Results from the numerical study of a Scania Euro3 engine shows a substantial reduction of pumping losses which causes a reduction in fuel consumption by up to 4.9 % depending on torque and engine speed. This is mainly due to the reduced pumping losses, but the DEP concept also offers the possibility to control the mass flow and therefore also the pressure ratio over the turbine. This gives the advantage of being able to keep the turbocharger in a high efficiency operating mode for a wide range of load and engine speeds.

KTH VETENSKAP OCH KONST

KTH CCGEx

LES of Flow Duct Acoustics

For Turbocharger Applications

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Abstract

Turbochargers are increasingly used in internal combustion engines and their acoustics is becoming an issue due to increased rotational speeds and improved noise control of other components. The objective with this project is to find CFD tools appropriate for the study of the acoustic properties of the turbocharger compressor. Both the reflection and transmission of incoming low frequency pulsations from the cylinders and the sound generation will be considered. To develop the methods, which are based on Large Eddy Simulation (LES), a simplified geometry consisting of a ducted orifice plate is used.

Background

Turbochargers are used in internal combustion engines to increase the power output at a given engine size and to improve the efficiency. They consist of a turbine and a compressor. The turbine, which is driven by the exhaust gases, drives the compressor that compresses the air going into the cylinders. Today turbochargers are used in most modern diesel engines and their use in gasoline engines is increasing. Due to this and the trend to make smaller turbochargers with higher rotational speeds their acoustics is becoming an issue.

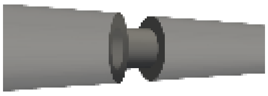
The acoustic properties of the turbocharger can be divided into one passive and one active part. The passive property is the damping effect the turbocharger has on incoming low frequency pulses, which are generated at the cylinders. The active property is the generation of high frequency noise.

To increase the understanding of the acoustics, with the aim of reducing the noise, it is desirable to couple the acoustics to a detailed study of the flow inside the machine. This area is difficult to access in an experiment, while computations can provide detailed information.

The objective is to find tools, based on Large Eddy Simulation (LES), which are appropriate for the study of the acoustic properties of a radial fluid machine. The aim is to be able to capture the flow inside the machine, how incoming pulses interact with this flow and the radiated noise and how it is correlated to sound generating mechanisms, i.e. specific flow phenomena.

Method

The study is carried out through compressible LES to fully capture the dynamics of the flow and its coupling to the acoustics simultaneously. To develop the method a simplified geometry, consisting of a ducted orifice plate, is used. The flow through this geometry is believed to have similar characteristics as that through a compressor, e.g. vortex generation, flow separation and shock waves at high Mach numbers.

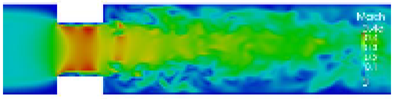


The orifice plate placed in a duct.

The project is divided into two parts. In the first part the passive properties are studied using an acoustic two-port model, which uses the acoustic pressure up- and downstream of the compressor to compute the reflection and transmission of incoming low frequency waves. Furthermore, the interaction between one wave, the plate and the flow will be studied in more detail. In the second part the active properties will be investigated by studying specific flow phenomena and their correlation to the radiated noise. The flow structures corresponding to specific sound generating frequencies are extracted with Dynamic Mode Decomposition (DMD).

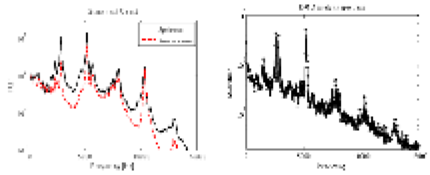
Results

Simulations have been performed for a 2 cm thick orifice plate, with an area contraction ratio of 0.36, placed in a square or a circular duct. Here, the flow filed in the circular ducts is shown for a mass flow of 50 g/s. It can be observed that as the air is forced through the orifice a jet is formed, creating a recirculation zone behind the plate, and vortex generation.

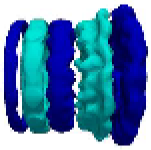


Flow through the orifice.

The sound generated by the flow above is shown below, together with a spectrum of the flow fluctuations in the orifice. Two distinct peaks can be observed in the generated sound, with corresponding peaks in the flow. The flow structures corresponding to these peaks are axisymmetric ring vortices and the structure at 5150 Hz is shown below. The flow spectrum also has a third peak. This is a non-axisymmetric flow structure, which does not generate sound.



Spectrum of generated sound (left) and of flow fluctuations (right)



Flow structure at 5150 Hz; iso-surfaces of positive and negative radial velocity

Conclusions

LES should be capable of resolving both the acoustics and the sound generating flow structures inside a rotating machine. The simplified geometry used has been shown to exhibit several of the flow characteristics seen in a compressor. Simulations of the sound generation show that high sound levels are generated at frequencies corresponding to axisymmetric flow structures.

Acoustics of Automotive Turbocharger

KTH CCGEx
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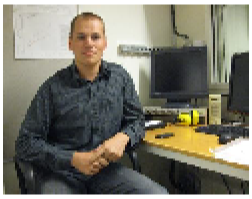
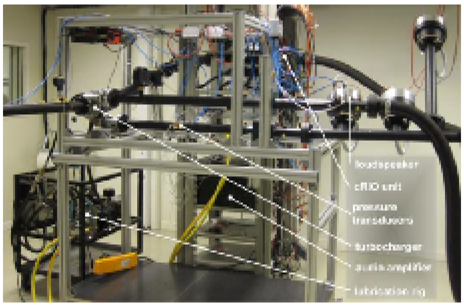


Abstract
Research and development for higher efficiency has led to engine downsizing where the use of exhaust gas driven turbochargers has currently raised the importance of turbocharger acoustics. The progressively tougher legislations on engine noise emissions have reached the stage where the turbocharger is critically focused on. Although the first exhaust-driven turbocharger was introduced almost a century ago the acoustical performance of these devices is still a field where relatively little published information exists. During this project a test facility has been developed to perform the acoustic characterization of turbochargers. The results for the sound transmission and -generation in the turbochargers are presented and the influence of the operating conditions of the unit has been analyzed.

Background

The application of turbochargers to internal combustion engines has increased considerably and nowadays almost all the diesel engines produced, together with the vast majority of modern high performance spark-ignition engines, are turbocharged. According to this trend, the acoustics of the turbo-chargers is increasingly becoming an issue. Despite the first exhaust-driven turbocharger was developed almost a century ago and the strong present motivation to implement them, there is still rather few research published on the acoustical performance of these devices.



KTH CCGEx turbocharger test facility.

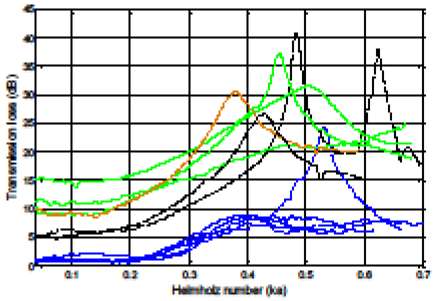
The turbocharger always consists of a compressor which is normally driven by an exhaust turbine. Both the turbine and the compressor have an influence on how the low frequency engine pulsations propagate in the gas exchange system. This is referred to as the passive acoustic property of the turbocharger. In this study three different turbochargers were analyzed. Measurements were performed in different operating point according to the compressor and turbine maps.

Method

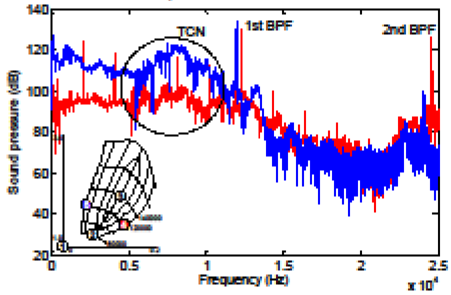
The turbocharger characterization facility has been established at the research competence centre for investigations on IC-engine gas management at KTH CCGEx in Stockholm. The ambition was to develop accurate experimental procedures for the determination of the scattering data for automotive turbochargers at realistic operating conditions selectable from the compressor and turbine charts. To determine sound transmission the automotive turbocharger was treated as an acoustic two-port.

Additionally to the measurements for the passive data, the facility can also be implemented to measure the sound generation by the turbo unit (the active properties).

Results



The transmission loss for three different turbo-compressors in upstream direction.



Comparison of sound pressure spectral densities between OP4 (red line) and OP5 (blue line) in outlet side of turbo-compressor.

Conclusions

The level of the TL results in the low frequencies (up to He 0.2) is determined by the losses in the system and increases with the mass flow. In the middle frequencies an upward slope is clearly recognisable. The angle of the slope is determined by the inner volume of the unit and it tends to increase when the volume increases. In the high frequency range characteristic peaks typically appear. The peaks originate from the resonances in the system - for example due to the cavity inside the waste gate actuator or due to the multiple sound paths through the rotor blades.

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Pressure sensitive paint (PSP) for rotating components

KTH CCGEx

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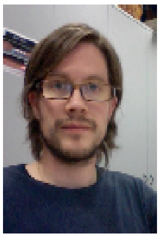

Abstract

This project aims at solving the problem of measuring pressure in high-speed rotational components (i.e. IC-engine turbo-chargers). The measurement technique chosen is a fast type pressure sensitive paint (PSP), an optical technique measuring pressure through luminescent quenching by oxygen. It has been shown that fast PSP is a promising technique that can produce fast, spatial resolved and accurate pressure measurements in unsteady flows.

Background

The pressure distribution on rotating surfaces, as for instance the turbo-charger compressor blades, is in practice impossible to measure using conventional pressure transducers. A new method is needed in order to be able to map the pressure distribution in these applications in order to make detailed investigations of rotational stall and surge phenomena.

Fast types of pressure sensitive paint (PSP) show promise in providing a solution to this issue, as well as a way of analyzing other engine related internal flows, such as pulsating flow in complex pipe systems.

Method

PSP is an optical technique to measure surface pressure in aerodynamic applications. It is composed of sensor molecules, or luminophores, embedded in an oxygen permeable binder. The luminophores are excited by light of appropriate wavelengths and through the mechanics of photoluminescence, light is emitted at lower energies. The presence of oxygen reduces the quantum yield of the system, relating air pressure and luminescent intensity. The basic experimental setup is illustrated in figure 1.

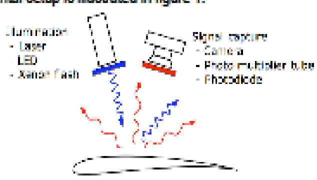

Figure 1. Basic experimental setup of PSP.

Due to the relatively slow diffusion rate of oxygen in the binder, traditional PSP is only able to resolve pressure fluctuations in the sub-Hz range. One method of overcoming this issue is by adding ceramic particles to the mix, effectively decreasing the binder thickness while maintaining the surface density of the luminophores. This mixture is a fast type PSP called polymer/ceramic pressure sensitive paint (PC-PSP) and is illustrated in figure 2.

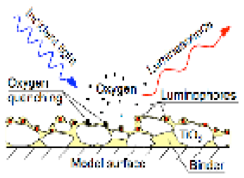

Figure 2. Schematic of conventional PSP.

Results

A combined pressure and temperature computer controlled chamber for calibration of PSP has been designed. The chamber has been tested with respect to temperature and pressure control. The temperature can be set to an accuracy better than 0.3°C.

A formula of fast responding PSP has first been statically calibrated in the chamber and thereafter run in a shock tube in order to find out the dynamic pressure response of the paint. The response time (illustrated in figure 3) was found to be about 0.3 ms. A method to evaluate the dynamic pressure response of the paint has been developed and has been presented at ICFD 2010 and at a workshop at JAXA in November 2010 (both in Japan).

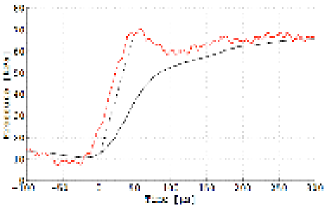

Figure 3. Ramp response from PC-PSP in shock tube showing estimated pressure (–), measured pressure (–) and corrected pressure(–).

The above-mentioned formula has been used to measure wall pressure inside a y-junction at periodic pressure fluctuations of between 40 and 80 Hz. An averaging phase locking technique has been used to increase the signal to noise ratio of the fast paint formulation and the results has been presented at Svenska mekanikdagar in June 2011 and at ISAIF10 in July 2011. An image showing a pressure pulse entering the y-junction (from the 45° branch) is shown in figure 4.

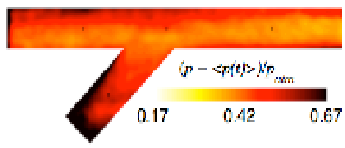

Figure 4. A pressure pulse entering the y-junction from the 45° branch.

Additional information

TeknL is planned to 2011/2012.
This project is supported by the Swedish Energy Agency.

Large Eddy Simulations for understanding Compressor Flow Instabilities

KTH CCGEx

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Abstract

The centrifugal compressor of an automotive turbocharger operates stable under a certain range of mass-flows. At low mass-flow rates, below a certain limit, flow reversal occurs in the compressor wheel, which results in amplification of velocity and pressure fluctuations. Severe such flow instabilities are affecting compressor performance and induce large loads on the blades under off-design conditions. The aim of this study is to understand the flow mechanisms leading to the surge condition in a centrifugal compressor. A systematic study is carried out to study the flow in a centrifugal compressor by using the Large Eddy Simulation (LES) approach.

Background

Emission regulations for personal transport vehicles are revised, becoming stricter, at regular time intervals. One possibility to accomplish the legislation limits is engine downsizing, which can be accomplished by turbocharging. The turbocharger increases the amount of charge in the combustion cylinder, which leads to a higher energy output when required. Compressors which can operate under a wide range of operating conditions are desired. The working range of the compressor is limited between the choke line (at high mass-flows) and surge (at low mass-flows). Surge is an instability that triggers a complete breakdown in compression, resulting in large pressure fluctuations and provoking severe backflow.

Setup and Method

Flow in a centrifugal compressor (w/o ported-shroud) of an automotive turbocharger has been simulated using the LES approach. The compressor wheel rotation is handled by the sliding mesh technique. Several operating conditions (i.e. different mass-flow rates) at a constant rotational speed of 64000 rpm have been computed, as plotted in Fig. 1. Experimental data obtained at Univ. of Cincinnati have been used for comparison purposes.

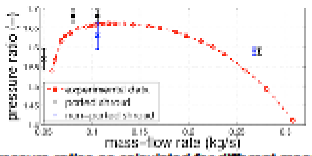

Figure 1. Pressure ratios as calculated for different mass flow rates from the LES data; comparison with experiments; 64000 rpm.

Results

With decreasing the operating mass-flow from the design condition, flow instabilities manifest in the centrifugal compressor, as shown in Fig. 2. Precursor instabilities to surge are the stall (stall cell generated by flow separation from impeller's blade surface - localized phenomenon within a blade passage) and rotating stall. Once a stall cell is generated within one of the blade passages, it blocks the incoming flow through that passage. The incoming flow is diverted due to the presence of the stall cell (its incidence angle changes). Thus, the blockage of one blade passage can influence the flow development in the neighboring blade passages and the flow interaction between the blade passages causes the stall cell to migrate from one blade passage to the next. This phenomenon is called rotating stall, which has been captured using LES and it was presented in [1]. These stall cells can be seen as regions of large velocity and pressure fluctuations. Stall results in lowering compressor efficiency. It also induces large vibrations in blades.

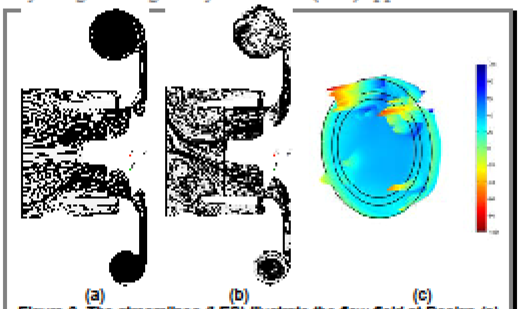

Figure 2. The streamlines (LES) illustrate the flow-field at Design (a) and Off-design (b) operating conditions. High-velocity jet-like structures exiting the shroud cavity at Off-design condition (c).

The effect of rotating stall is local to the compressor. However, when such instabilities evolve into the more damaging surge, large flow fluctuations through the whole compression system exist. Surge results in mechanical vibrations and has a particular noise associated with it. The occurrence of the surge phenomenon is a function of the rotational speed of the centrifugal compressor and it is difficult to predict the onset of this phenomenon accurately. The shroud cavity is a passive flow control device, which is thought to improve the operation range of the compressor. Flow simulations with ported and non-ported shroud geometries showed (consistently with experiments) that flow disturbances are damped with the ported-shroud and this technology improves the performance of the compressor. Under unstable conditions (near the surge line) high velocity jet-like structures exit the shroud cavity and interact with the incoming flow, as shown in Fig. 2 (c). The present study will analyze the dynamic changes into the flow responsible for triggering surge.

References

[1] Jyothishkumar V., Mihaescu M., Semlitsch B., and Fuchs L., *Numerical Flow Analysis in a Centrifugal Compressor near Surge Condition*, 43rd AIAA Fluid Dynamics Conference and Exhibit, AIAA 2013-2730, 2013.

[2] Jyothishkumar V., Semlitsch B., Mihaescu M., Fuchs L. and Gutmark E., *Investigation of the Surge Phenomena in a Centrifugal Compressor using Large Eddy Simulation*. ASME Paper, IMECE 2013-66301, 2013.

KTH CCGEx

Compressor Maps for Real Engine Installations

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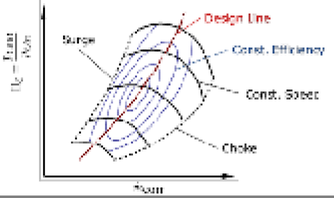
Abstract

This project aims at improving turbocharger compressor maps for installations in automotive engines, where the inlet and outlet piping influence the compressor characteristics close to the surge regime. Using the knowledge gained from other investigations within the CCGEx Compressor off-Design project, as well as own compressor measurements, a model shall be set up to predict compressor behavior near the surge regime as a function of different inlet geometries.

Background

Modern internal combustion engines are often equipped with a turbocharger in order to increase the power density and reduce friction losses. The turbocharger is usually not developed in-house, but supplied by an external manufacturer. When selecting and installing a turbocharger on an engine, the turbocharger compressor map is an important basis for the decision. It gives the pressure increase over the turbocharger compressor as a function of its speed and mass flow. This map is determined by measurements on a gas stand by the turbocharger supplier. However, the gas stand does not accurately simulate the turbocharger on-engine behavior, since it uses different inlet and outlet piping than an engine installation, as well as steady flow. This has been shown to influence the compressor characteristics, especially in operating regimes at lower mass flows (e.g. [1], [2]). A detailed understanding of, and a model to quantify the differences in compressor behavior for different inlet geometries, have, however, so far not been obtained.



The CoD Project

The Compressor off-Design (CoD) project is a research project within the Competence Center for Gas Exchange (CCGEx), involving research personnel from KTH Mechanics, MWL, and KTH ICE, as well as industry partners. Starting from the working hypothesis that the observed difference in compressor behavior for different inlet geometries near surge is a result of the compressor flow, and more specifically compressor rotating stall in this regime, the following objectives have been formulated:

- Improve the understanding of compressor flow in centrifugal compressors close to the surge regime
- Develop/Adopt methods for stall identification
- Quantify the upstream pipe geometry effects on the compressor map

Different methods are applied in order to achieve these objectives: The flow field at the compressor inlet as a result of the upstream geometry is evaluated using LDV and PIV measurements. In order to understand the compressor flows, fast type pressure sensitive paint measurements in the impeller, and large eddy simulation (LES) of the whole compressor flow field are used. Furthermore, acoustic measurements are deployed to identify characteristic frequencies in the flow, which can help in classifying the stall phenomena according to literature.

Rotating Stall in Centrifugal Compressors

Centrifugal compressors in turbochargers are usually equipped with vaneless diffusers. The main advantages of vaneless diffusers are a wide operating range and low cost, both of which are important factors for automotive turbochargers. For these compression systems, three basic types of rotating stall have been described in literature (e.g. [3]):

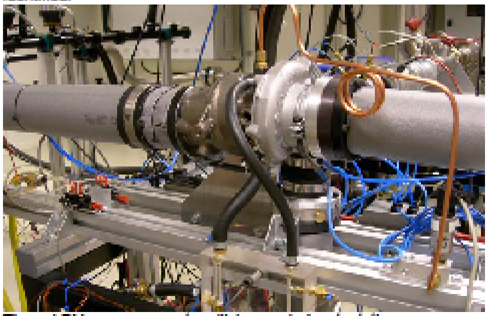
a. Progressive impeller rotating stall
b. Abrupt impeller rotating stall
c. Vaneless diffuser rotating stall

Those types are usually characterized by typical stall cell velocities, numbers of stall cells, and velocity oscillation amplitudes. Especially type (a) depends heavily on the inlet flow field.

Investigations

As part of the CoD project, the investigations focus on the influence of the compressor inlet geometry on the compressor behavior near the surge operating regime.

The first investigations will focus on a top-down approach: Different inlet geometries are installed upstream of the compressor, and the speed lines, especially close to the surge regime, are measured. This way, the way in which the compressor map changes can be identified.



Then, LDV measurements will be carried out at the compressor inlet for the different inlet geometries. The flow field here influences the occurrence and characteristics of compressor instabilities.

In a later step, the results from these studies, as well as the understanding of compressor instabilities gained within the CoD project, will be used to try to set up a model. The model should quantify the effect of the compressor inlet flow on the compressor map close to the surge regime. It should also be compatible with engine development tools and processes with respect to available input data and computing effort.

References:

[1] Galindo, J., et al. "Measurement and Modelling of Compressor Surge on Engine Test Bench for Different Intake Line Configurations.", SAE Technical Paper, 2011.

[2] Greitzer, E. "Surge and Rotating Stall in Axial Compressors I: Theoretical Compression System Model." Journal of Engineering for Gas Turbines and Power, Vol. 98 (1976): 190-198.

[3] v. d. Braembussche, R. "Centrifugal Compressors Analysis & Design", von Karman Institute, Rhode Saint Genese, Belgium, 2013.

KTH CCGEx

Pulsating flow in complex channels– experiments

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Abstract

The air flowing through the exhaust manifold of the internal combustion engine to the inlet of the turbocharger is highly pulsating and turbulent. Travelling through curved pipe sections the air enters the turbine under the effect of centrifugal (from the acute curvature), inertia and viscous forces resulting in a three-dimensional, non-symmetric flow field. Additionally, vortical structures are being formed due to the co-existence of these forces which change shape and behaviour under a pulse period. Although this complex flow field is directly connected to the inflow conditions to the turbocharger and modelling of such flows could improve the efficiency of the engine, it is yet far from being understood.

Background

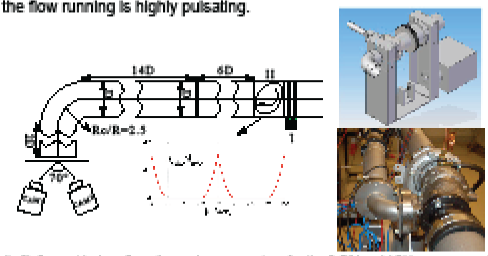
The gas flow in the exhaust system of an internal combustion engine is quite complex due to several complications such as complex geometry (bends, junctions), pulsating flow, compressibility, high temperatures, partly transonic flow etc. In order to understand how the flow to the turbine should be modelled a good model of the flow into and in the exhaust manifold, as well as to the turbine needs to be established. Numerical studies of such flow systems are/have been studied within KTH CCGEx.

Experimental Techniques

Due to the high complexity of the flow field under study, different experimental techniques need to be employed and tested in order to fully understand the different flow phenomena under highly pulsatile and turbulent conditions.

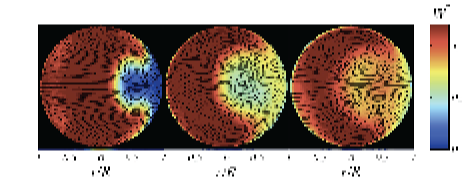
Hot- and cold-wire anemometry (HWA/CWA) have been employed in order to obtain information on the statistics of the flow with high time resolution. For this purpose an in-house automatic traversing mechanism (depicted to the right). Laser Doppler Velocimetry (LDV) measurements have been supplemented for validation purposes, while Stereoscopic Particle Image Velocimetry (S-PIV) measurements have been performed in order to obtain simultaneously the three velocity components and capture the secondary motions in a cross-sectional field.

Additional measurements using the vortex mass flow meter, developed by Laurantzon et al. [Meas Sci Technol 21:123001 (2010)], were performed in order to determine the phase-resolved turbine maps when a sharp bend is mounted at the inlet of the turbine and the flow running is highly pulsating.

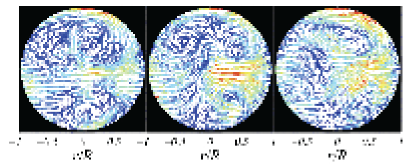


(Left) Geometrical configuration and camera set up for the S-PIV and LDV measurements. D=40.5mm, R_c=51mm. I) smoke injection inlet, II) rotating valve. (Right, Top) Automatic traversing mechanism for the rotation of the HW/CW measurements. (Right, Bottom) Pipe bend (D=40.5mm, Rc=51mm) mounted at the inlet of the turbocharger (Garrett) for the pressure ratio measurements.

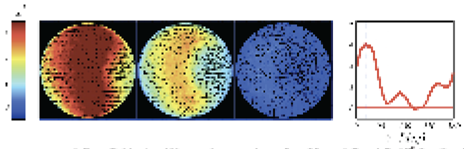
Impressions



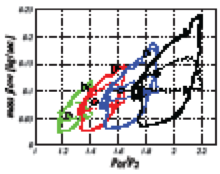
Time-averaged velocity flow field at 0.2 D (left), 1 D (middle) and 2 D (right) downstream the 90 ° pipe bend at a Dean number De=1.5x10[illegible]. The streamwise component is shown as the background contour map while the in-plane components as streamlines. Quantities with asterisk indicate scaling by the bulk speed.



Snapshots at various time instances of the in-plane velocity vector field 2 D downstream the pipe bend for De=1.5x10[illegible].



Phase averaged flow field at a Womersley number of α=30 and De=1.5x10[illegible] for the 2 D downstream station from the pipe bend. Right: Phase averaged streamwise velocity (red line) at the centerline of the pipe. The phase angle corresponding to the shown phase averages is indicated through the dashed lines.



Turbine map for 55 (green), 80 (red), 105 (blue) & 130 g/sec (black) at 40 Hz pulsation frequency. Solid lines: inflow, dashed lines: outflow. Circles indicate average values

Presentations and Publications:

[1] Kalpakli, A., Örlü, R., Tillmark, N. & Alfredsson, P.H. 2010 *Experimental investigation on the effect of pulsations on turbulent flow through a 90 degrees pipe bend*, ICJWSF, Sept 27-30 2010, Cincinnati, USA.

[2] Kalpakli, A., Örlü, R., Tillmark, N. & Alfredsson, P.H. 2011 *Pulsatile turbulent flow through pipe bends at high Dean and Womersley numbers*, ETC13, 12-15 Sept 2011, Warsaw, Poland.

[3] Kalpakli, A., Örlü, R. & Alfredsson, P.H. 2011 *Dean vortices in turbulent flows–rocking or rolling?* J. Vis., doi:10.1007/s12650-011-0108-8

[4] Kalpakli, A., Örlü, R. & Alfredsson, P.H. 2011 *Reynolds and swirl number effects on turbulent pipe flow in a 90 degree pipe bend*, APS 20-22 Nov 2011, Baltimore, USA

[5] Kalpakli, A., Örlü, R. & Alfredsson, P.H. 2011 *Dancing in the pipe*, selected to appear on the online gallery of fluid dynamics (APS virtual pressroom)

[6] Kalpakli, A., Örlü, R., Tillmark, N. & Alfredsson, P.H. 2012 *Experimental investigation on the effect of pulsations on exhaust–manifold related flows aiming at improved efficiency*, (submitted) 10th Int. Conf. Turbochargers and Turbocharging (ImechE), May 15-16 2012, London, England

KTH VETENSKAP OCH KONST

KTH CCGEx

Pressure sensitive paint (PSP) for rotating components

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Abstract

This project aims at solving the problem of measuring pressure in high-speed rotational components (i.e. IC-engine turbo-chargers). The measurement technique chosen is a fast type pressure sensitive paint (PSP), an optical technique measuring pressure through luminescent quenching by oxygen. It has been shown that fast PSP is a promising technique that can produce fast, spatial resolved and accurate pressure measurements in unsteady flows.

Background

The pressure distribution on rotating surfaces, as for instance the turbo-charger compressor blades, is in practice impossible to measure using conventional pressure transducers. A new method is needed in order to be able to map the pressure distribution in these applications in order to make detailed investigations of rotational stall and surge phenomena.

Fast types of pressure sensitive paint (PSP) show promise in providing a solution to this issue, as well as a way of analyzing other engine related internal flows, such as pulsating flow in complex pipe systems.

Method

PSP is an optical technique to measure surface pressure in aerodynamic applications. It is composed of sensor molecules, or luminophores, embedded in an oxygen permeable binder. The luminophores are excited by light of appropriate wavelengths and through the mechanics of photoluminescence, light is emitted at lower energies. The presence of oxygen reduces the quantum yield of the system, relating air pressure and luminescent intensity. The basic experimental setup is illustrated in figure 1.

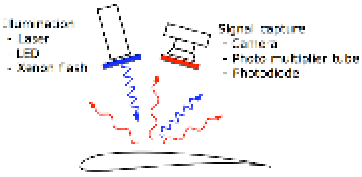

Figure 1. Basic experimental setup of PSP.

Due to the relatively slow diffusion rate of oxygen in the binder, traditional PSP is only able to resolve pressure fluctuations in the sub-Hz range. One method of overcoming this issue is by adding ceramic particles to the mix, effectively decreasing the binder thickness while maintaining the surface density of the luminophores. This mixture is a fast type PSP called polymer/ceramic pressure sensitive paint (PC-PSP) and is illustrated in figure 2.

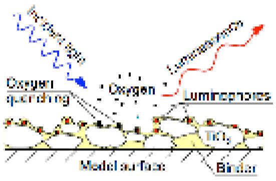

Figure 2. Schematic of conventional PSP.

Results

A combined pressure and temperature computer controlled chamber for calibration of PSP has been designed. The chamber has been tested with respect to temperature and pressure control. The temperature can be set to an accuracy better than 0.3°C.

A formula of fast responding PSP has first been statically calibrated in the chamber and thereafter run in a shock tube in order to find out the dynamic pressure response of the paint. The response time (illustrated in figure 3) was found to be about 0.3 ms. A method to evaluate the dynamic pressure response of the paint has been developed and has been presented at ICFD 2010 and at a workshop at JAXA in November 2010 (both in Japan).

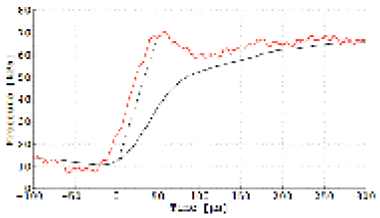

Figure 3. Ramp response from PC-PSP in shock tube showing estimated pressure (–), measured pressure (–) and corrected pressure(–).

The above-mentioned formula has been used to measure wall pressure inside a y-junction at periodic pressure fluctuations of between 40 and 80 Hz. An averaging phase locking technique has been used to increase the signal to noise ratio of the fast paint formulation and the results has been presented at Svenska mekanikdagar in June 2011 and at ISAIF10 in July 2011. An image showing a pressure pulse entering the y-junction (from the 45° branch) is shown in figure 4.

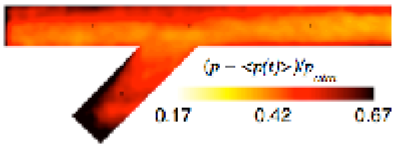

Figure 4. A pressure pulse entering the y-junction from the 45° branch.

Additional information

TeknL is planned to 2011/2012.
This project is supported by the Swedish Energy Agency.

KTH CCGEx

Rotating machines and innovative noise control

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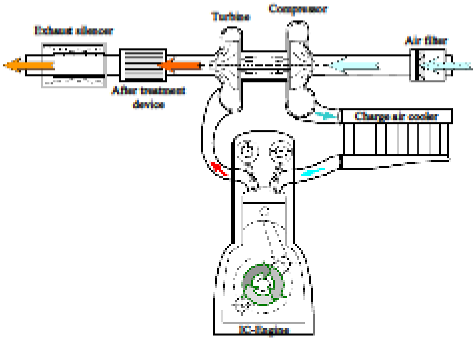
Abstract

The goal of this project is to develop improved techniques for studying scattering of sound and sound generation from rotating machines, e.g. turbo-chargers or ducted fans in general. In particular, to extend previous work to high amplitudes and the measurement of the in-duct sound power produced by the machine. The experimental work will both combine advanced acoustic and fluid dynamic experimental tools (e.g. PIV). Parallel works involve computational fluid dynamics (CFD) modeling with large eddy simulation (LES) technique. The efforts will be run in order to develop a more in depth understanding of the generation as well as the reflection/transmission of sound. Studies of noise control by surfaces consisting of micro-perforated plates or compact mufflers are also planned. The work is part of a Marie-Curie network on aero-acoustics named FlowAirS (see www.flowairs.eu).

Background

The potential of higher noise emission in living or working environments is increasing with the number of rotating machines e.g. turbo-chargers. Therefore, it is important to put simultaneous effort into the acoustical research to maintain acceptable noise levels.

The application of turbo-chargers to internal combustion (IC) engines has increased considerably e.g. nowadays almost all the diesel engines and the vast majority of modern spark-ignition engines are turbo-charged. Hence, the acoustics of the turbo-chargers has become an important issue. Despite the fact that first turbo-chargers were developed almost a century ago and the current strong motivation to implement them, there is still rather few research published on the acoustical performance of these devices.

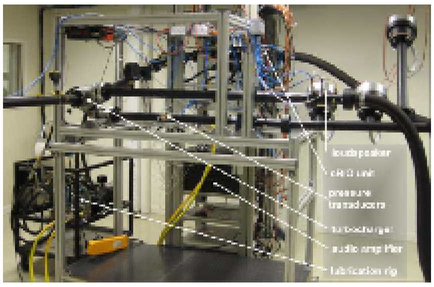


A schematic representation of an turbo-charger supercharging an IC-engine

Generally, the turbo-charger consists of a compressor which is driven by an exhaust turbine. Both the turbine and the compressor affecting the propagating acoustic low frequency pulsations in the gas exchange system of the IC engine. This is referred to as the passive acoustic property of the turbocharger. Also, there is an active acoustic property i.e. an additional sound generation.

Investigation

The turbo-charger acoustic characterization facility has previously been established at the research competence centre of gas exchange (CCGEx) at KTH in Stockholm, see www.ccgex.kth.se. The facility will be used to obtain a complete acoustical characterization of a turbo-charger i.e. to determine accurate acoustical scattering data (passive property) and source data (active property) at realistic operating conditions. These conditions are including the high gradients of pressure, temperature and flow velocity i.e. it is a challenging measurement task. In order to improve the overall quality of the measurements and expand the possible measurement range the acoustic excitation needed for passive acoustic measurements will be extended to the higher levels. In addition, recently developed new accurate measurement models of the acoustic power produced by the machine will be employed.



KTH CCGEx turbocharger test facility.

Parallel to the experimental work, the computational fluid dynamics modelling, mainly with the large eddy simulation technique, will be carried out. Combined with respective experimental investigation, it is expected to develop more in depth understand of the scattering and generation of sound.

The studies will also focus on innovative acoustic materials e.g. micro-perforated panels. Together with compact silencers they will be treated as a potential sound control solution for turbo-charger applications.

KTH CCGEx

Nonlinear Acoustic Properties Of An In-Duct Orifice

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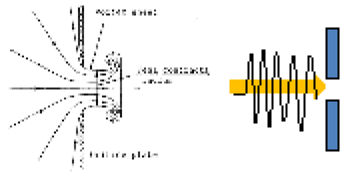
Abstract

This project experimentally investigates the acoustic properties of an orifice with bias flow under medium and high sound level excitation. The test included no bias flow and two bias speeds for three different frequencies. Experimental results are compared and discussed with theory. It is shown that bias flow makes the acoustic properties much more complex compared theory and with the no bias flow case, especially when velocity ratio between acoustic particle velocity and mean flow velocity is near unity.

Background

Orifice plates and perforates appear in many technical applications where they are exposed to a combination of high acoustic excitation levels and either grazing or bias flow or a combination. Examples are automotive mufflers and aircraft engine liners. Taken one by one the effect of high acoustic excitation levels, bias flow and grazing flow are reasonably well understood. However, each combination of them increases complexity of fluid mechanism as well as the difficulty to model it. Acoustic non-linearity takes place at fairly low acoustic excitation levels (120dB or less).The non-linear losses are associated with vortex shedding at the outlet side of the orifice or perforate openings. Losses are significantly increased in the presence of bias flow, since it sweeps away the shed vortices and transforms the kinetic energy into heat, without further interaction with the acoustic field.

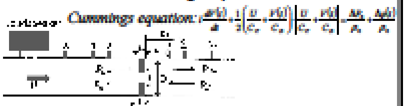


Acoustic nonlinearity with bias flow

The purpose of the project is to make a detailed experimental study of the transition between the cases when high level nonlinear acoustic excitation is the factor determining the acoustic properties to the case when bias flow is most important. This is related to if high level acoustic excitation causes flow reversal in the orifice or if the bias flow maintains the flow direction. Acoustic properties, such as impedance, Rayleigh conductivity and absorption coefficient are discussed.

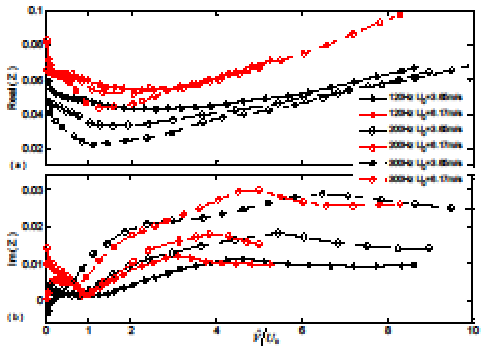
Method

The test object was an orifice plate with 3mm thickness and 6mm hole diameter. The orifice plate was mounted in a rigid tube with a diameter of 40mm. Pure tone pressure was used and we used two-microphone method to identify the sound wave components on each side. Two bias flow cases and three frequencies were taken into consideration. Theoretically harmonic balance method was used to analyze the model based on the Cummings equation.

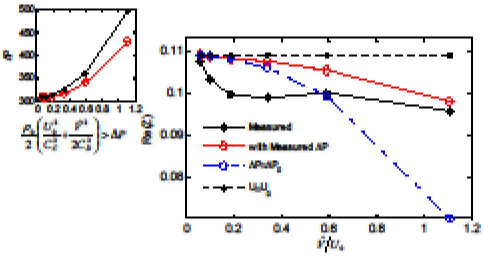


Experimental configuration

Results



Normalized impedance in the orifice as a function of ratio between acoustic particle velocity and mean flow velocity



Steady pressure difference and resistance as a function of ratio between acoustic particle velocity and mean flow velocity

Conclusions

Bias flow makes the acoustic properties of the orifice much more complex. Three regions were identified in terms of the ratio between acoustic particle velocity and mean flow velocity being: (I) smaller than unity, (II) around unity and (III) larger than unity. For region I there was a decrease in resistance and a variation in reactance with velocity ratio. In region II both parts of the impedance had a minimum. In region III resistance increased while the reactance firstly had an increase and then approached a constant value. The steady pressure difference over the orifice neither keeps constant nor increases so much as when the mean flow velocity keeps constant. High level acoustic excitation causes the decreasing of the mean flow velocity and it makes resistance decrease in region I and II.

Detailed modeling of single & double turbines

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KTH CCGEx

Abstract

As the emission legislation is getting tougher and tougher for car manufacturers in Europe and in other parts of the world the need for newer and more efficient engines has risen. One way of dealing with the emission problem is downsizing the engine; a smaller engine has less geometrical losses i.e. frictional losses. One effective way of downsizing an engine is to give it a turbocharger. A turbocharger increases the engine efficiency and power output without increasing the fuel consumption or emissions as much.

Background

Turbo-charging (TC) is essential for enabling down-sizing and for enabling emission reduction while maintaining or enhancing combustion efficiency. The energy in the hot exhaust gases can be utilized in order to compress the air that is provided to the cylinders and thereby the utilization of the combustion chamber volume is enhanced. For faster response and for better operation over a wider range of engine load one has proposed using 2 staged TC (for example in tandem). This project shall explore some issues that can be related to such systems.

When doing calculations on turbochargers in the industry today one is often restricted to 1D simulation tools in which the turbochargers are implemented as maps. These maps are commonly from the manufacturer and measured at constant massflow and low temperatures. This is very far from the environment the turbochargers are in, where the flow is highly pulsatile and the temperatures are much higher. Part of this project is aimed at looking at the differences between steady flow and pulsating flow and how much the turbine performance is changed by this.

Method

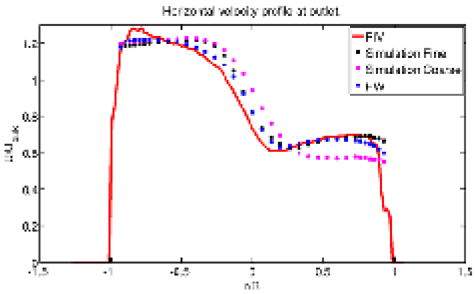
For this project Unsteady RANS and Large Eddy Simulations are being performed on a single stage turbine. Both steady and pulsating flow is being simulated and different inflow conditions are being applied.

For the steady cases experiments have been performed at the Saab Gas-stand in Trollhättan where a wide range of flow conditions were measured extensively, both in hot and cold conditions. For pulsating flow no measurements are currently available for the same geometry.

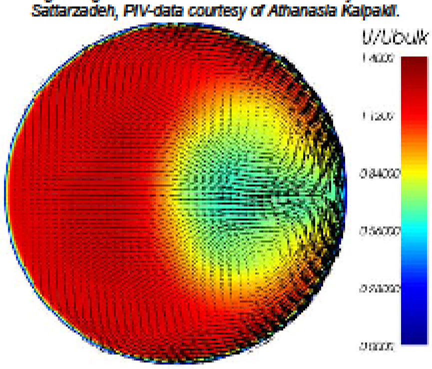
To validate the simulation software an easier case has been setup where flow in a bended pipe is being studied. Within the center measurements of the same case has been performed so the data available for validation is good and easily accessible.

Results

For the bended pipe flow simulations comparisons have been made between LES and experiments (PIV and HWA).



When comparing the simulations (2 grids shown) with both PIV and HWA good agreement is seen. HWA-data courtesy of Sohrab Sattarzadeh, PIV-data courtesy of Athanasia Kalpakli.



Mean velocity divided by bulk velocity at the outlet after the pipe bend. Both dean vortices can be seen and scalar levels are quantitatively similar to those of the PIV.

Conclusions

For the bended pipe good agreement between measurements and simulations can be shown for the outlet velocity profile.

For the bended pipe simulations the software is predicting the flow accurately compared to experiments.

KTH CCGEx

EGR-Systems for Diesel Engines

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Abstract

EGR is an important sub system within gas management. Future combustion concepts may need large amounts of EGR to reduce NO_X. This project deals with various aspects of EGR both from a system perspective, i.e. how the EGR system thermo- and gas dynamically interacts with other parts of the engine as well as the performance of a number of specific components, as e.g. connection points, pipe geometries and heat exchangers. Issues to take into account are pressure losses, heat transfer, mixing of EGR with fresh air, as well as particle and soot deposition. A special issue is to be able to deliver high amounts of EGR in any driving situation. In this part of the project different ways to achieve EGR as well as boost pressure are analysed and benchmarked. The fuel economy can be worsened if the system is not optimised for best fuel economy.

Background

To comply with future emission legislation, engine manufacturers will have to reduce the emissions of the engines dramatically. One way to achieve this is the use of after treatment devices; the other is to reduce the formation of emissions during combustion. EGR is a proven method for reducing NO_x formation by decreasing the local temperature during combustion. The extensive use of EGR leads to a reduced engine efficiency. The scope of this project is to find systems with a good EGR-performance, thus delivering the desired amount of EGR, while maintaining the efficiency of the engine at a high level.

Method

Two test engines, a passenger car diesel and a heavy duty diesel, have been run on steady state load points containing full load as well as emission cycle relevant points. Corresponding GT-Power models have been calibrated to match the measured data. The passenger car engine was even run in transient and the model calibrated to the engine behaviour.
For the analysis of EGR-distribution from cylinder to cylinder, a fast four-channel CO_2 analyser is used as well as standard CO_2 analysers.

The calibrated GT-Power models are then used to analyse the performance of different EGR systems. Figure 1 shows some of the systems that have been analyzed in this project.

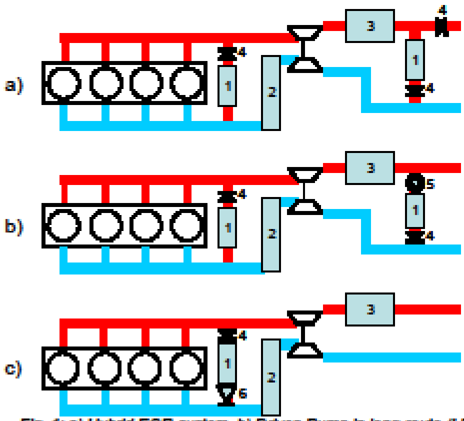

Fig. 1: a) Hybrid EGR-system, b) Driven Pump in long-route (LR), c) Reed valve in short-route (SR), with: 1. EGR-cooler, 2. Intercooler, 3. DPF, 4. Throttle / Valve, 5. Pump, 6. Reed valve

Results

Figure 2 shows a comparison of the brake efficiency achieved on a passenger car diesel engine for the different systems shown in Figure 1.

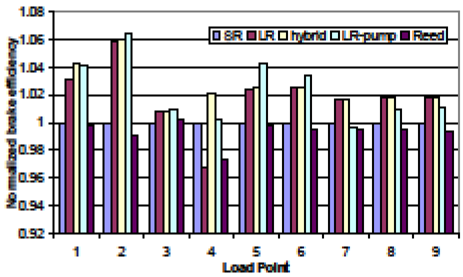

Fig. 2: Normalized brake efficiency for different EGR-systems

Figure 3 shows the load step response of the engine when run with different distributions of the EGR between the long-route and the short-route path in the hybrid system.

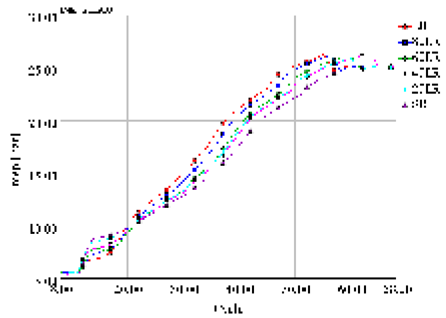

Fig. 3: IMEP for a full load transient at 2000 rpm

Conclusions

This part of the project showed that a hybrid EGR system has advantages regarding transient response and fuel consumption compared to a standard short-route system. Further systems are analyzed in the project and a study about EGR-distribution is conducted.

KTH CCGEx

EGR Mixing

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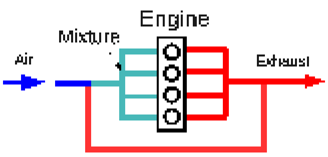
Abstract

This project deals with turbulent mixing processes occurring in internal combustion engines, when applying exhaust gas recirculation (EGR). One of the practical problems when applying EGR is the non-uniformity of the mixture among and inside the cylinders deteriorating the engine and emission performance.

Background

Emission legislation has become more and more strict throughout the last decades. This is problematic for engine manufacturers, who have to introduce new techniques in order to comply with these regulations. Most problematic for Diesel engines are the NOx emissions. NOx is formed at high combustion temperatures. One way to reduce the peak combustion temperatures is to lower the oxygen concentration of the combustion gas. This is done by EGR. A portion of the exhaust gases is recirculated and mixed with the intake air.



EGR working principle.

The issue that this project is addressing is the mixture non-uniformity of the exhaust gases and the intake air, which has shown to have negative effects on the engine and emission performance.

Method

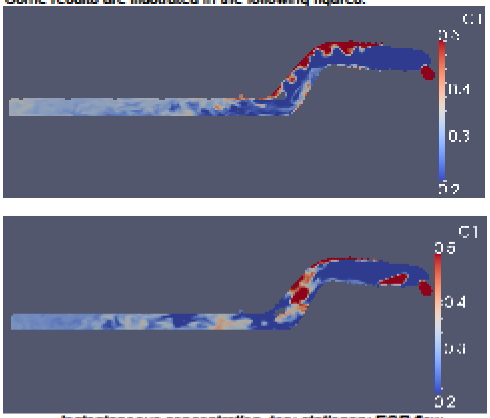
Since the distribution of EGR is difficult to measure, the aim of the project is to compute it by CFD. Computing the turbulent flow and the turbulent mixing process is, however, not a trivial task. Different model approaches, RANS and LES, are therefore applied. The shortcomings and advantages of these approaches are assessed, first in simplified geometries with stationary and pulsating inflow conditions, then in realistic geometries with boundary conditions from GT-Power simulations. Furthermore, the sensitivity of the results to the boundary conditions shall be evaluated.
The GT-power simulations are preformed by another Ph.D.-student inside the center, Simon Reifarth, who is also performing experimental measurements of the EGR distribution. It will be tried to validate the results in close cooperation.

T-junction

As a first approach, mixing processes were studied in a T-junction with stationary and pulsating inflow conditions. The main results in stationary flow are that RANS predicts fundamentally different flow structures from the LES computations. Dean vortices that occur due to the flow curvature are broken up by high turbulence intensities occurring downstream of the junction. The flow instabilities due to high velocity gradients are the main mechanism promoting turbulent mixing. When applying pulsating inflow conditions, these instabilities are amplified, if the pulsation frequencies are in the same order as the natural instability frequencies. Since RANS models the scales of these instabilities, these resonance effects cannot be predicted by RANS.

Scania manifold

Computations on a 6-cylinder Diesel engine manifold provided by Scania were performed applying RANS and LES. In this first study generic boundary conditions were applied with both stationary and pulsating EGR flow.
Some results are illustrated in the following figures:



Instantaneous concentration, top: stationary EGR flow, bottom pulsating EGR flow

Instantaneous concentration differences of up to 10 % are found in the flow into the cylinders. Pulsations are important for the mixture formations and are travelling down the fairly far downstream without being diffused.

Conclusions

The studies on the engine manifold show that the effect of pulsating boundary conditions is important. Moreover, it has been found that the smoothing effect of URANS does not seem to be adequate for accurate mixing computations for cases, where turbulence is governing the mixing.
Future computations will therefore focus on LES computations with boundary conditions from GT-Power and/or experiments.
The results summarized here have been presented in the licentiate thesis 'On the computation of Turbulent Mixing Processes with application to EGR in IC-engines including the two conference articles:
'LES of the turbulent mixing process in a T-junction with stationary and pulsating inflow conditions', presented at ISAIF10, and
'Computation of mixing processes related to EGR', presented at TSFP7.

KTH CCGEx

Flow in exhaust valve ports and manifolds

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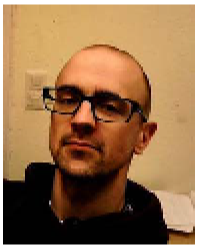


Abstract

Vehicles with internal combustion (IC) engines fueled by hydrocarbon compounds have been used for more than 100 years for ground transportation. During the years and in particular in the last decade, the environmental aspects of IC engines have become a major political and research topic. Following this interest, the emissions of pollutants such as NO_x, CO_2 and unburned hydrocarbons (UHC) from IC engines have been reduced considerably. Yet, there is still a clear need and possibility to improve engine efficiency while further reducing emissions of pollutants. This project aims at increasing understanding of the gas flow in the exhaust part of the gas exchange system by computational methods. The flow is shown to exhibit strong unsteady features that may affect the efficiency of the gas exchange system.

Background

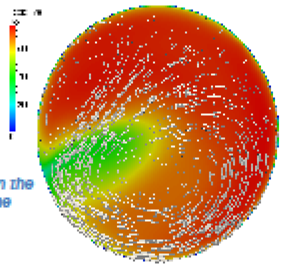
The maximum efficiency of IC engines used in passenger cars is no more than 40% and considerably less than that under part load conditions. One way to improve engine efficiency is to utilize the energy of the exhaust gases to turbocharge the engine. While turbocharging is by no means a new concept, its design and integration into the gas exchange system has been of low priority in the power train design process. One expects that the rapidly increasing interest in efficient passenger car engines would mean that the use of turbo technology will become more widespread. The flow in the exhaust ports and manifold determines the flow into the turbine, and thereby the efficiency of the turbocharging system. This project aims at increasing understanding of the flow in the exhaust port and manifold with respect to unsteadiness, the generation of large scale flow structures and generation of flow losses.

Method

The flow in these engine components were analyzed by computational methods, both Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES).

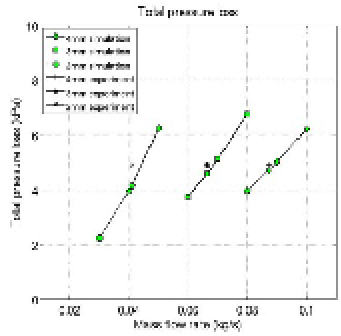
Results

Generation of structures at the valve body visualized by the λ_2 criterion



Large scale vortices in the port downstream of the valve

Results



Comparison of experimental and computational results

Conclusions

The flow in the exhaust port and manifold is shown to be highly unsteady with strong secondary flows and significant regions of separated flow. These phenomena *can not* be investigated by common engineering methods like RANS and, in order to gain insight and increase the understanding of these flows, more advanced methods (LES) must be used. As a result of the increasing demands of efficiency, design of future gas exhange components will need to account for the unsteady features of the flow in an accurate way and thus use LES as a tool in the design process alongside with RANS.

KTH VETENSKAP OCH KONST

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Analyzing Flow Losses in the Exhaust Port of an Internal Combustion Engine

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Abstract

About 30-40% of the energy potential is lost in the exhaust gases after combustion in an Internal Combustion (IC) engine. The exhaust gases are hot and therefore rich of energy, which can be recuperated in a turbocharger or a Stirling engine to increase engine efficiency. The exhaust port of a truck engine forms the interface between the IC engine and the energy-recovering device. Hence, energy losses are highly unwanted in this section of the engine. Numerical simulations are performed to enhance the understanding for the generation of flow associated loses and to establish groundwork for further one-dimensional flow modeling used in engine design.

Background

One-dimensional IC engine analysis utilizes databases and operation maps for the individual components, as e.g. bent pipes, compressors or turbines. The exhaust port including the valves is too complex to be approximated from a database. Energy is lost in the exhaust port, either directly or through formation of flow structures that enhance dissipation. Commonly, the exhaust port is modeled by experimentally evaluated discharge coefficients, which are obtained by measure-ments for fixed valve lifts at low pressure-drops. Using these values for an arbitrary valve motion, the total pressure loss is approximated. However, higher pressure-drops may occur when the flow chokes. Hence, this procedure might lead to remarkable errors, when the flow bursts through the port at small valve lifts. The numerical simulations performed with this project illustrate the importance of accounting that effect.

Setup and Method

The exhaust port geometry of an IC heavy-duty Diesel engine, the D12 from Scania, has been used in the investigations. Large Eddy Simulations (LES) of the governing equations for compressible flow have been carried out using the commercial finite-volume solver STAR CCM+. The implied differences due to the choice of method for simulating the exhaust process from an engine cylinder are assessed. Thus, simple cases using fixed positions for valve and piston are contrasted with the cases where static valve and moving piston, and moving valve and moving piston are considered. The generated flow phenomena are compared within the cases.

Results

An illustrative realization of the flow-field is shown in Fig. 1. The near valve region is a major source of losses. Due to the presence of the valve, an annular, where the high-velocity flow follows the valve stem into the port. Flow separation occurs immediately downstream of the valve seat on the walls of the port and on the surface of the valve body. Strong longitudinal, non-stationary secondary flow structures (i.e. in the plane normal to the main flow direction) are observed in the exhaust manifold. Such structures can degrade the efficiency of a possible turbine of a turbocharger located downstream on the exhaust manifold. The secondary flow motion induces shear stresses at the wall, which are a source of generated losses. High peak values in the wall shear stress are observed, where the high velocity flow impinges the port walls and the valves (see Fig. 2).
LES simulations and Unsteady Reynolds Averaged Navier-Stokes (URANS) have been carried out. Due to the dissipative nature of the URANS approach is the separation of the annular jet over predicted and too high pressure losses are estimated. Thus, the flow evolves different and the peak losses are predicted in different regions.

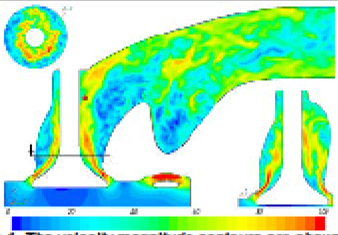

Figure 1. The velocity magnitude contours are shown for a particular valve lift.

A comparison between the approaches of modeling the valve at a fixed location using a mass-flow to resemble the piston, simulating the piston motion and keeping the valve fixed, and simulate the moving valve and the motion of piston have been performed. It has been found that the flow-field is predicted at too high velocities by modeling the valve at a constant lift. For the static case (fixed valve and modeled piston) the flow chokes, while the Mach-number stays for the moving valve and moving piston in a regime below 0.7 at the same valve lift. The distribution of total pressure for these two cases shows a similar shape, but the amplitudes are distinct. Separation bubbles form more clearly in the case of fixed valve fixed piston than for the moving case.

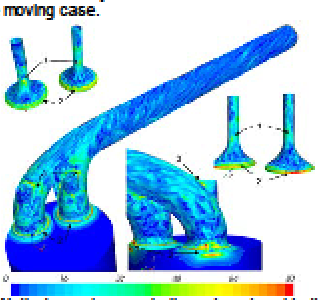

Figure 2. Wall-shear stresses in the exhaust port indicating the friction losses.

Additional information

This project is supported by the Chinese Scholarship Council. PhD defense is planned in Dec. 2013.

In-cylinder flow

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Abstract

As the emission legislation is getting tougher and tougher for car manufacturers in Europe and in other parts of the world the need for newer and more efficient engines has risen. In-cylinder flow involves different scales and structures as well as moving geometries and unstationary boundary conditions. Additionally, in-cylinder flow has a profound effect on engine emissions and fuel consumption. Therefore, understanding generation of these structures and the effect of compression is essential for reducing engine emissions.

Background

In-cylinder flow can be divided into several distinct phases. The flow enters the cylinder during the intake phase, forming an unsteady hollow jet around the valves. The unsteady jet creates a very turbulent in-cylinder flow field effectively mixing residual gases with fresh air. The incoming jet is also responsible for creating the large scale structures, swirl and tumble. During late part of intake and early compression the small scale turbulence settles while large scale structures remain.

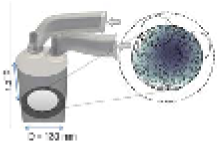
During the second half of the compression any remaining turbulence will be amplified. In addition, swirl and tumble are affect by the changing geometry. Generally, swirl angular momentum is assumed to survive compression while tumble momentum is know to breakdown. If the piston and cylinder head is designed to produce squish (Pressing flow inwards by a rapid reduction of volume close to the cylinder walls), this will produce an organized motion creating turbulence and have dynamical effect on swirl and tumble. During combustion (and definitely from a Diesel spray) turbulence will increase and affect the large scale motions. During the power stroke turbulence is sharply suppressed and at Bottom Dead Center (BDC) most of it has settled.

Focus of this project is to understand the creation and evolution of large scale structures and turbulence from the intake up to start of injection. In addition, identify which parameters can be adjusted to obtain desired flow field.

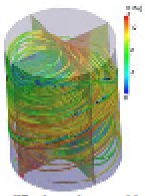
Method

In-cylinder measurements are very difficult due to a number of reasons as well as the difficulty to change the geometry and extract the effect on specific parameters. Therefore, Large Eddy Simulations (LES) has been chosen as the main method in this project.

Initially, flow structures created during intake were studied using LES coupled with Particle Image Velocimetry (PIV) in a steady swirl test rig. Thereafter, the effect of compression on a swirling/tumbling flow has been studied in a simplified engine.



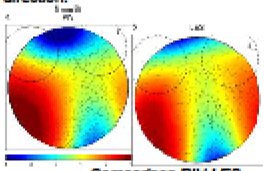
Swirl Test rig



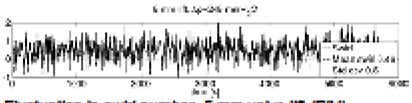
Simplified engine and initial flow field

Results, Swirl test rig

Comparison between LES simulations and PIV experiments show qualitatively good agreement. It is shown that at low valve lifts the fluctuations in swirl is greater than the mean swirl number. In-cylinder turbulence created during intake is axisymmeteric with one dominant direction.



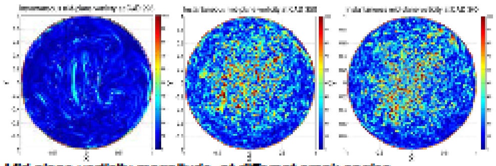
Comparison PIV LES



Fluctuation in swirl number, 5 mm valve lift (PIV)

Results, Compression swirling/tumbling flow

It is found that vorticity-dilatation is responsible for redirecting flow kinetic energy introduced by the piston into small scale turbulence. The conversion is most rapid around the time of maximum dilatation.



Mid plane vorticity magnitude, at different crank angles