**Engine Downsizing**

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***Abstract***

*Thegrowingimportanceinresearchinautomotivedevelopmentisthereplacementofbiggerengineswithcompactyetpowerfulones,andthereductioningreenhousegasesthroughexhaust.Differentstrategiesareappliedtocomplywithstringentemissionregulationsthatareenforcedonglobalautomotivemarket.InternalCombustion(IC)EngineDownsizingisthemethodthatservesboththepurposesofprovidingtheneededpowerandreducingfuelconsumption.Thisreportpresentsabriefinformationonvariousenginedownsizingtechniquesused,theadvantagesofthesetechniques,theirlimitationsandtheireffectsontheperformanceoftheengine.Thereportalsoprovidesusafewboostingmethodsusedforadownsizedenginetoimproveitsperformanceasofahighercapacityengine,asdownsizinganICengineonlymaycauseadipinperformancewhileimprovingotherfactors.Thereportdrawsattentiontowardstheconclusionsresultedfromsomeexperimentsonthedownsizedengines.Alsoabriefinformationisprovidedontheeffectsofenginedownsizingonanengine.*

***Keywords:****ICEngine,Downsizing,ExhaustGas,Turbocharger,Supercharger,Valvetrain*

**1.Introduction**

*1.1ConceptofEngineDownsizing*

1Enginedownsizingisdefinedastheuseofasmallerengineinavehiclethatprovidesthepowerofalargerengine,throughtheuseofrecenttechnologies.Thetermgenerallyrelatestotraditionalinternalcombustionenginespoweredbypetrolanddiesel.Enginedownsizingisatrendingconceptforvehicleenginemanufacturerstoprovideefficientyetpowerfulengines.

*1.2Necessityofdownsizing*

Thegrowingconcerninautomotivedevelopmentistheformationofgreenhousegasesthroughexhaustflow,primarilycarbondioxide.Legislationsandincreasingpublicawarenessaboutglobalwarmingareleadingvehiclemanufacturerstoreducetheircarbonfootprint.Originalequipmentmanufacturersaremakingconstanteffortstoreducegreenhouseemissionsandfuelconsumptionbydevelopingthroughdifferentareasthoughmostoftheemissionandfuelconsumptionreductionisseenthroughincreasingtheefficiencyofpowertrain.Enginedownsizingisconsideredthemosteffectivestrategytoimprovetheefficiencyofpowertrain(OliverLang,2004)

**Fig.1**Sizedifferencebetweenanonturboengineontheleftandturbochargedengineontheright,bothproducingsamepower.

**2.TheRationalebehindEngineDownsizing**

Adownsizedengineoffersdifferentbenefitstothewellbeing.Theyareasfollows:

1)ReductioninCO2andNO2emissions:Enginedownsizinghasprovedagreatdipinemissionduetolesserfuelconsumptionandotherimportantfactorsexplainedbelow.

2)Fuelconsumptionreduction:Optimizationoftheintakeandexhaustvalvetimingatlowenginespeedwithscavengingleadstoareducedresidualgascontentinthecylinder.

3)Decreaseintheweightofengineblock:Generallydownsizinganengineisdonebyreducingthenumberofcylinders.Thishelpsinthereductionofweightoftheengineandthustheloadontheenginedecreases.

4)Lessersweptvolumebypiston:Duetodecreaseinthedisplacementofthepiston,thereisadecreaseinfrictionbetweenthepistonandtheenginebore.

Hencethelossesduetofrictionarereduced.This

addstothebenefitofenginedownsizing.

**3.TypesofEngineDownsizingtechniquesused:**

Thebasisofmostdownsizingprocessesisincreasingtheperformanceby

1)Usingturbochargers

2)Usingsuperchargers

3)Usingtwin-charging

Newmethodsthatsupportdownsizedenginesareuseofthetechnologiesbelowand/orwiththethosementionedabove

1)Directfuelinjection(DI).

2)Advancedexhaustgasrecirculation(EGR).

3)Variablevalvetiming(VVT).

UseofTurbochargerorSuperchargeralonehasnowbecomeobsolete.Thereasonisthattheuseofthemwithoutanysupplementarydevicehascomparativelylesseradvantages.NewertechnologieslikeTurbochargedDirectFuelInjectionandVariableValveTimingarewidelyusedinrecenttimesforcarsandlightmotorvehicles.

**4.DownsizingusingaTurbocharger**

Despiteofitslowerdisplacement,theperformanceofadownsizedenginecanbemaintainedbyinjectingmoreairintothecombustionchambertoburnadditionalfuel.Turbochargingprovidestheenginewiththemassofairneededtoensurehighlyefficientandcleancombustion.

Inbothpetrolanddieselvehicles,theturbocharger

comprisestwoassemblies:acentrifugalcompressorandaturbine.Hotgasesrotatetheturbinewhichrotatesthecompressorasbothareconnectedviaasameshaft.

Thecompressorcomprisesanimpellerandadiffuser,housedinthecompressorcasing.Theimpelleracceleratestheairdrawnfromtheatmosphereandforcestowardsthediffuser.Thediffuserslowsthefast-

movingairwhichraisesitspressureandtemperature

inthecompressorhousing.Thecompressedairisthendirectedtotheengine.Thisway,moreairisinjectedintothecombustionchamberandburnstheadditionalfuelneededtomaintainenginepower.

*4.1ProblemsinTurbocharging*

Oneofthemainproblemswiththeuseofonlyaturbochargeristhattheydonotprovideanimmediatepowerboostwhenyouaccelerate.Ittakessometimeforaturbinetogetuptothespeedbeforeboostisproduced.thisresultsinafeelingoflagwhenyouaccelerate,andthenthecarlungesaheadwhentheturbochargerstartsoperating.

Onewaytodecreasethisturbolagistoreducetheinertiaofrotatingpartsmainlybyreducingtheirweight.Thisallowstheturbineandcompressortoacceleratequicklyandprovidetheboostwithoutanylag.

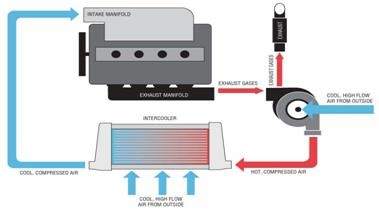
Theflowofexhaustgasesthroughtheturbineandcompressoriscarefullycontrolledtopreventtheturbochargerfromoverchargingathighenginespeedsandalsotomaintaintorqueatlowerenginespeeds.

*4.2UsinganIntercooler*

Anintercoolerisamechanicaldeviceusedtocoolafluid,includingliquidsorgases,inmulti-stageheatingprocess,typicallyinaheatexchangerthatremoveswasteheatinagascompressor.Theyarewidelyknownasair-to-airorair-to-liquidcoolers.Theyimprovethevolumetricefficiencyofinternalcombustionenginesbyforcedinductionwithnearlyisobariccooling.

Theefficiencyoftheinductionsystemisincreasedbyintercoolersbyreducinginductionairheatcreatedbythesuperchargerorturbocharger.Thisremovestheheatofcompressionoftheinletgas.

Adecreaseinintakeairchargetemperaturehelpsintheinductionofamoredenseintakechargeintotheengine.Theloweringoftheintakeairtemperaturealsoeliminatesthedangerofpre-detonation(knocking)ofthefuel/aircharge.Thispreservesthebenefitsofmorefuel/airburnperenginecycle,increasingtheoutputoftheengine.(source:Honeywell)



**Fig.2**SchematicofthepositionofIntercoolerinavehicle(source:[www.turbosmart.com.au](http://www.turbosmart.com.au))

**5DevelopmentsinaTurbocharger**

*5.1Two-Stageturbocharger*

Aconventionalturbochargingsystemspresentstallingissuesatlowspeeds.Infact,themaximumcompressor

flowratemustbeaboutthesameofthefullboreengine,inordertodeliverthesameairflowatmaximumpower.However,atlowspeed,boostpressureshouldbehigher,forcompensatingthedisplacementreduction.

Thisproblemissolvedbyatripleturbocharger.Thetripleturbochargerisconceptuallysimilartoa2-stagesystem(RainerGolloch,*etal*,2005),theonlydifferencebeingthatthehighpressurestageismadeupoftwoparallelmachines,insteadofone.Thelowpressure

stageconsistsofabiggerturbochargerthatdeliversa

flowrateabouttwotimeshigherthanthatoftheturbochargerinaconventionalsystem.Conversely,thehighpressureturbochargersaremuchsmallerandarecompletelyby-passedathigherenginespeeds.Inthe

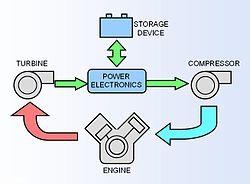
triplelayout,withaproperchoiceofeachmachine,the

turbochargersofbothstagesmayoperateathighefficiencyconditions,allovertheenginespeedrange

(CarloAlbertoRinaldini,*etal*,2015).Thetripleturbochargerismorecomplexthanatwin-turbo,from

twopointsofview:electroniccontrolandpackaging.

*5.2Hybridturbocharging*

Ahybridturbochargerisanelectricturbochargerconsistingofahighspeedturbine-generatorandahighspeedelectricaircompressor.Highelectricalefficiencyisobtainedasthereisnomechanicallinkagebetweentheturbineandthecompressor.Thehybridturbochargerreferstoaserieshybridsetup,inwhichcompressorspeedandpowerareindependentfromturbinespeedandpower.Thisdesignflexibilityleadstofurtherimprovementsinturbineandcompressorefficiency.

**Fig.3**SchematicofaHybridturbochargersystem

*5.2.1Operatingmodes*

*A)Acceleration*

Whenthedriverpressesthethrottle,thehybridturbochargerinitiallyactslikeanelectricsupercharger.Thecompressormotorispoweredfromtheenergystorageandallowsittoacceleratetofulloperatingspeedinashorttimeinterval.Thisrateofaccelerationeliminatestheturbolag.

*B)Charging*

Athighenginespeedsexcessenergyisgeneratedbytheturbinethanrequiredbythecompressor.This

excessenergyrechargestheenergystorageforthenextaccelerationphaseortopowersomeoftheauxiliaryloadssuchasanelectricairconditioningsystem.

*C)Steadystate*

Forthemajorityofthetimethehybridturbochargerisoperating,thecompressorandturbinepowerwillbematched.Herethehybridturbochargerefficientlytransferstheelectricitybetweentheturbineandcompressor.

**6.DownsizingusingaSupercharger**

Asuperchargerisanaircompressorthatincreasesthepressureordensityofairsuppliedtoaninternalcombustionenginebutwiththehelpofmechanicalpoweroftheengineandnottheexhaustgaseslikethatofaturbocharger.

Theyareoftwotypesofsuperchargers,mechanicallydrivenandelectricallydriven.Mechanicallydrivensuperchargersmayabsorbasmuchasathirdofthetotalcrankshaftpoweroftheengineandarelessefficientthanturbochargers.Electricallydrivensuperchargersdonotdrawdirectpowerfromtheengine,unlikeconventionalsuperchargers.Atlowenginespeed,electricsuperchargersdonottakemuchenergyandaremucheffective.

*6.1AdvantagesofaSupercharger*

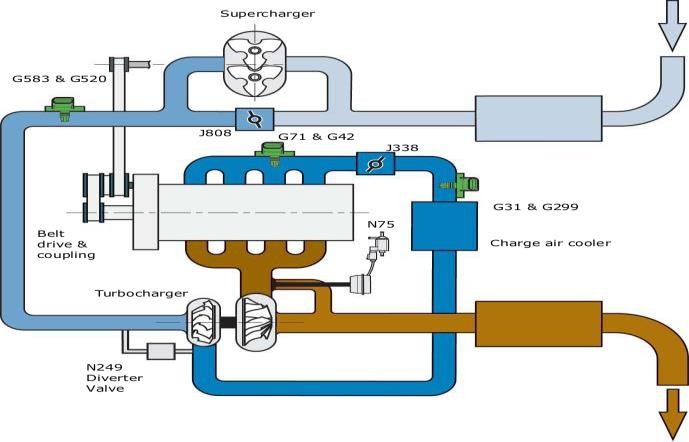
Themainadvantageofsuperchargerisbetterthrottleresponse,aswellastheabilitytoreachfull-boostpressureinstantaneously.Engine-drivensuperchargersapplyboostindirectproportiontotheenginerpm.

*6.2ProblemswithusingonlyaSupercharger*

Thethermalefficiencyislesswhencomparedwithasimilarturbocharger,becauseturbochargersuseexhaustgasenergythatwouldnormallybewasted.Theeconomyandthepowerofaturbochargedengineareusuallybetterthantheengineswithonlyasupercharger.

**7.DownsizingusingTwinCharger**

Twinchargerisacombinationofanexhaust-driventurbochargerandanengine-drivensupercharger.Asuperchargeroffersexceptionalresponseandlow-rpmperformanceasithasnolaglikethatoftheturbocharger.Boththecomponentsworktogethertogivemaximumoutputmitigatingtheweaknessesoftheother.



**Fig.4**Schematicshowingthetwinchargingsystem

(source:VolkswagenClubGTI)

*7.1AdvantagesofusingaTwincharger*

Thepropercombinationofthetwocanofferazero-lagwithhightorqueatlowerenginespeedsandincreasedpoweratthehigherspeeds.Twinchargingisthereforedesirableforsmall-displacement,especiallythosewithalargeoperatingrpm,sincetheycantakeadvantageofanartificiallybroadtorquebandoveralargespeedrange.Hencetwinchargingisveryusefulindownsizedengines.

Twinchargingdoesnotrefertoatwin-turboarrangement,butratherwhentwodifferentkindsofcompressorsareused.Theymightbeinaseriesorinaparallelcombination

*7.2ProblemsinusingaTwincharger*

Themainproblemoftwinchargingisthatthecomponentsandcomplexandexpensive.Usually,toprovidebetterresponse,smoothnessandadequatepowergainoverasingle-compressorsystem,expensiveelectronicand/ormechanicalcontrolsmustbeused.

**8.DownsizingusingTurbochargedDirectInjection**

**(TDI)**

*8.1Spark-ignitionenginedownsizingusingTDI*

Spark-ignition(SI)enginedownsizingisnowestablishedasa‘megatrend’intheautomotiveindustry,providingasitdoesanaffordablesolutiontothetwinissuesofreducingtailpipeCO2emissionsandimprovingfueleconomywhileprovidingimproveddrivabilityfromgasolineengines.

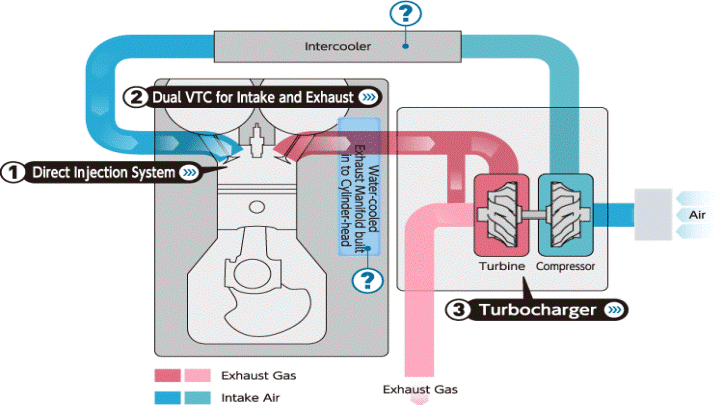
Theadvantagesofdownsizinga4-strokespark-ignition(SI)enginestemchieflyfromshiftingtheoperatingpointsusedintheenginemapforanygivenflywheeltorque,sothatthethrottleiswider-opentothebenefitofreducedpumpinglosses.

InTDIsystemafuelinjectorspraysatomizedfueldirectlyintothecombustionchamberofeachcylinder,ratherthanthepre-combustionchamberthatwasused

inolderengines.Theengineusesturbochargertoincreasetheamountofairenteringtheenginecylinders.TDIsystemisalsousedwithanintercooler.Incombination,theyimproveengineefficiency,andthereforeprovidegreaterpoweroutputswhilealsodecreasingemissionsandprovidingmoretorquethanthenon-turboandnon-directinjectionpetrolenginecounterpart.

Becausetheseengineshaverelativelylowdisplacementandarequitecompact,theyhavealowsurfacearea.Thisreducesheatlossesthroughtheenginesurface,andtherebyincreasesengineefficiency,

attheexpenseofslightlyincreasedcombustionnoise.



**Fig.5**SchematicofTDItechnology(source:Hondaworldwide)

*8.2EffectsofTDIonengineperformance*

TheBMEPoftheenginecanbeincreasedsignificantlyduetotheeffectiveincreaseinknockresistanceaffordedbythedirectinjectionofthefuelintothecylinderduetoitsevaporativeeffectandalsotheintroductionoffuelcanbedelayeduntilaftertheexhaustvalvesareshut.

Atpresent,thesparkretardationisnecessarywhenoperatingsuchenginesonpetrol.Thisensuresthattheseveryhighlevelsofcylinderpressurecannotbe

achievedinpractice,butwithfutureenginetechnology

andfueldevelopmenttheymaybeapproachedevenwhenoperatingonrelativelylow-octaneregularpetrol.(Turner,*etal*,2010)

**9.UseofVariableValveTiming(VVT)inDownsized**

**Engines**

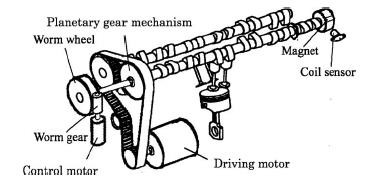
Variablevalvetiming(VVT)isusedinsparkignitionenginestoimprovefueleconomy,reduceNOxgas,andincreasepeaktorqueandpower.Thevariablevalveliftalsomakesanimportantroletotheperformanceoftheengine.

Withoutvariablevalvetimingorvariablevalvelift,thevalvetimingisthesameforallenginespeedsandconditions,thereforecompromisesarenecessary.An

engineequippedwithavariablevalvetimingactuationsystemisfreedfromthisconstraint,allowing

performancetobeimprovedovertheengineoperatingrange.

Anenginerequireslargeamountsofairwhenoperatingathighspeeds.However,theintakevalvesmayclosebeforeenoughairhasenteredeachcombustionchamber,reducingperformance.Ontheotherhand,ifthecamshaftkeepsthevalvesopenforlongerperiodsoftime,aswitharacingcam,problemsstarttooccuratthelowerenginespeeds.Thiswillcauseunburntfueltoexittheenginesincethevalvesarestillopen.Thisleadstolowerengineperformanceandincreasedemissions.(AtulGupta,etal,2013)



**Fig.6**SchematicofVVTusingcontrolmotor

*9.1EffectsofVVTonEnginePerformance*

Duringmostofitsaveragelife,aroadengineisrununderlowloadandlowspeedconditions.Itisknownthatloadreductioninspark-ignitionenginesistraditionallyrealizedbyintroducingadditionallossesduringtheintakestrokebymeansofathrottlevalve.Intheseoperatingpoints,theengineefficiencydecreasesfromthepeaktovaluesdramaticallylower.Theoptimizationofintakeandexhaustvalvetimingcanprovidesignificantreductionsinpumpinglossesatpartloadoperation.

*9.2ChallengesinVVTtechnology*

VVTneedstwoorthreeextragearsandabeltdrivewhichincreasesthesizeofthedrivetrain.Duetoengagementofactuatorswithcams,therearechancesofincreasedfrictiononthecamsurfacethatmaycausedegradationofthecam.

Themainfactorpreventingthistechnologyfromwideuseinproductionautomobilesistheabilitytoproduceacosteffectivemeansofcontrollingthevalvetimingundertheconditionsinternaltoanengine.Thevalvetimingeventshavetooccuratprecisetimestoofferperformancebenefits.Electromagneticandpneumatic[camlessv](https://en.wikipedia.org/wiki/Camless)alveactuatorsofferthegreatestcontrolofprecisevalvetiming,but,in2015,arenotcosteffectiveforproductionvehicles.(AtulGupta,*etal,*

2013)

**10.Advancedexhaustgasrecirculationfor**

**DownsizedEngines**

InICengines,exhaustgasrecirculation(EGR)isanitrogenoxide(NOx)emissionsreductiontechniqueusedinpetrol/gasolineanddieselengines.

*10.1WorkingofEGR*

EGRworksbyrecirculatingaportionofanengine'sexhaustgasbacktotheenginecylinders.ProvidingonlyEGRactuallydropstheperformanceofengineby10-13%,butwithrecenttechnologiesoptimizingthecontrolvariableslikeboostpressure,A/Fratioandsparkadvance,sameperformanceisachievedasthatofanenginewithoutEGRsystem.(E.Galloni,*etal*,2013)

*10.2EffectsofEGRinDownsizedEngines*

EGRoperationallowshigherboostpressurevaluesandleanerA/Fmixturesatagivenknockintensitylevel.Inparticular,whenEGRisutilized,aproperoptimizationofthemainenginecontrolvariables(i.e.boostpressure,airtofuelratioandsparkadvance)allowsachievingthesameperformanceleveloftheenginerunningwithpureA/Fcharge,meanwhiletheexhausttemperatureandknockintensityremainthesameandthespecificfuelconsumptionsignificantlydecreases.(E.Galloni,*etal*,2013)

**11.EffectsofEngineDownsizingonLosses**

Adownsizedenginetendstoproducelesserlossintermsoffrictionduetoreducedsurfacearea.Enginedownsizingreducesmechanicallosses,butatalowerratethanisproportionaltodisplacement.Pumpinglossesaredependentontheoperatingconditionsandmustbecalculatedforeachdrivingmode.Buttheyarestillreducedduetodownsizing.(RyujiroNozawa,*etal*,

1994)

**Conclusions**

Enginedownsizingisacontinuousdevelopingprocessandmanynewmethodsofachievingbetterpowerandfuelefficiencyatlowenginecapacityarebeingdeveloped.ForanICengine,possiblebenefitsinfuelconsumptionarebetween10and30%dependingonthedegreeofdownsizingandthecombustionprocess.Thoughthemaximumspeedofavehicleisreducedbydownsizing,therearemanyexperimentswhichsuggesttheexistenceofoptimalenginedisplacement.Itisexpectedthatthecombinationofturbocharging,directinjectionandvariablevalvetimingwillbecomethestandardinthefuture.Highperformanceenginevariantscanberealizedwithoutmajordrawbacksintheirusablespeedrange.Itisalsoobservedthatfrictionlossesforunitdisplacementincreaseinsmallerengines,andtheuseoffavorableregionsonthefuel-consumptionmapmayimprovethefueleconomy.

Thankstodownsizing,thepetrolanddieselenginesofthefuturecouldhavejusttwocylindersanda

displacementoflowerthanaliter,andproviderequiredtorqueandpowerwithoutproducinghigh

amountofpollutants.

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