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# Determination of THIV, PHD, and ASI

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### F1 INTRODUCTION

he European Committee for Normalization (CEN) has adopted the Theoretical Head Impact Velocity (THIV) and associated Post-Impact Head Deceleration (PHD), and the Acceleration

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Severity Index (ASI) as measures of occupant risks for purposes of evaluating results of a crash test (130–132). They are presented herein with the hope and expectation that U.S. testers will determine and report these indices. The goal of this effort is (a) to develop a database from which comparisons can be made between the THIV, ASI, the fl ail space indices recommended herein, and other measures of occu- pant risk, and (b) to provide a basis from which future test and evaluation procedures can be formulated by and harmonized between the United States, CEN, and other countries.

### F2 A GUIDE TO THE MEASUREMENT OF THE THEORETICAL HEAD IMPACT VELOCITY (THIV) AND THE POST-IMPACT HEAD DECELERATION (PHD)

F2.1 GENERAL

The Theoretical Head Impact Velocity (THIV) concept has been developed for assessing occupant im- pact severity for vehicles involved in collisions with road vehicle restraint systems (74). The occupant is considered to be a freely moving object (head) that, as the vehicle changes its speed during contact with the safety feature, continues moving until it strikes a surface within the interior of the vehicle. The magnitude of the velocity of the theoretical head impact is considered to be a measure of the impact severity.

The head is presumed to remain in contact with the surface during the remainder of the impact period. In so doing, it experiences the same levels of acceleration as the vehicle during the remaining contact period (Post-Impact Head Deceleration—PHD) (74).

F2.2 THEORETICAL HEAD IMPACT VELOCITY (THIV)

It can be assumed that at the beginning of vehicular contact with the test article, both the vehicle and the theoretical head have the same horizontal velocity, *V*0, vehicular motion being purely translational.

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During impact, the vehicle is assumed to move only in a horizontal plane, because high levels of pitch, roll, or vertical motion are not of prime importance unless the vehicle overturns. This extreme event does not need to be considered, as in this case the decision to reject the candidate system will be taken on the basis of visual observation or photographic recording.

Two reference frames are used, as indicated in Figure F-1. The fi rst of these is a vehicular reference C*xy*, *x* being longitudinal and *y* transversal; the origin *C* is a point at or near the vehicle’s center of mass, where two accelerometers and a rate gyroscope are typically installed (see Section 4.3.2 for recom-

mended procedures to determine accelerations and yaw rate at *C* if the instrumentation cannot be placed

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at or near the center of mass). Let *xc* and *yc* be the accelerations of point *C* in ft/s2 (m/s ), respectively,

along the *x* and *y* vehicle axes, recorded from the two accelerometers, and Ψ the yaw rate (in radians per

.

second), recorded from the gyroscope ( &*x*& positive forward, *ÿ* positive to right hand side, and Ψ positive

clockwise looking from above).

The second reference frame is a ground reference *OXY*, with the *x* axis aligned with the initial vehicular velocity *V*0, and the origin *O* coinciding with the initial position of the vehicular datum point *C*.

*Xc*(*t*), *Yc*(*t*) are the ground coordinates of the vehicle reference *C*, while *Xb*(*t*), *Yb*(*t*) are the ground coor- dinates of the theoretical head (see Figure F-2).

With these defi nitions and simplifying hypotheses, vehicle and theoretical head motion can be com- puted as follows.

*x*

Ψ

C

*y*

*X*

*x*

*V* 0

Ψ0

*x*0 T heoretic al H ead

*Y*

C

*y*

Figure F-1. Vehicle and Ground Reference Frames

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##### VEHICULAR MOTION

Initial condition: at time *t* = 0,

⎧⎪ *X c* = 0

⎨

*Yc* = 0

Ψ = Ψ0

⎪⎩ *X*& *c* = *V* 0

*Y*&*c* = 0

Ψ& = 0

(Eq. F2-1)

The yaw angle Ψ is computed by integration of the yaw rate Ψ& :

Ψ (*t* )= ∫

*t*

Ψ& *dt* + Ψ0

(Eq. F2-2)

0

Then, from the components of vehicular acceleration in ground reference,

⎧⎪ *X*&&*c* = &*x*&*c* cos Ψ − &*y*&*c* sin Ψ

⎨

⎪⎩*Y*&&*c* = &*x*&*c* sin Ψ + &*y*&*c* cos Ψ

(Eq. F2-3)

Vehicular velocity and position are computed by integration:

⎧

⎪ *X*& *c* = Δ*X*& *c* + *V*0

*t*

Δ*X*& *c* = ∫

*X*& *c dt*

⎪

⎨

⎪

⎪*Y*&*c*

⎩

= Δ*Y*&*c*

Δ*Y*&*c*

0

*t*

∫

= *Y*&*c dt*

0

(Eq. F2-4)

*t*

⎧

⎪ *X c* = ∫

Δ*X*& *c dt* + *V*0*t*

⎪

⎨

⎪

⎪*Yc*

0

*t*

= ∫ Δ*Y*&*c dt*

(Eq. F2-5)

⎩ 0

##### THEORETICAL HEAD MOTION RELATIVE TO GROUND

Initial condition: at time *t* = 0

⎧ *X b* = *x*0 cos Ψ0 = *X* 0

⎪

⎨

⎪⎩ *X*& *b* = *V*0

*Yb* = *x*0 sin Ψ0 = *Y*0 *Y*&*b* = 0

(Eq. F2-6)

Then, if the theoretical head continues its uniform motions:

*Xb* = *V*0*t* + *X* 0

*Yb* = *Y*0

(Eq. F2-7)

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##### THEORETICAL HEAD MOTION RELATIVE TO VEHICLE

Vehicular components of the relative velocity of the theoretical head are:

⎧*vx* (*t* ) = − Δ*X*& *c* cos Ψ − Δ*Y*&*c* sin Ψ + *yb* Ψ&

⎪

⎨

⎪*v* (*t* ) = Δ*X*& sin Ψ − Δ*Y*& cos Ψ − *x* Ψ&

⎩ *y c c b*

(Eq. F2-8)

Coordinates of the theoretical head with respect to the vehicle’s frame can be computed by the formula:

*t*

⎧

⎪*xb* (*t* ) = Δ*Xb* cos Ψ + Δ*Yb* sin Ψ Δ*Xb* = *X* 0 − ∫

Δ*X*& *c dt*

⎪

⎪ where:

⎨

⎪

⎪

0

(Eq. F2-9)

*t*

⎪ *yb* (*t* ) = − Δ*Xb* sin Ψ + Δ*Yb* cos Ψ Δ*Yb* = *Y*0 − ∫

Δ*Y*&*c dt*

⎩⎪ 0

##### TIME OF FLIGHT

Notional impact surfaces inside the vehicle are assumed to be fl at and perpendicular to the *x* and *y* vehicular axes (see Figure F-2). The distances of such surfaces from the original head position (fl ail distances) are *Dx* forward and *Dy* .

*V* 0 *yb*

*xb*

C

*X b*

*D x*

*x*0

C

*D y D y*

Figure F-2. Impact of the Theoretical Head on the Left Side

The time of fl ight of the theoretical head is the time of impact on one of the three notional surfaces in Figure F-2, i.e., the shortest time *T* when one of the three following equalities is satisfi ed:

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*xb* (*T* )= *Dx* + *x*0 or

*yb* (*T* )= *Dy*

or *yb* (*T* )= −*Dy*

(Eq. F2-10)

The standard values of the fl ail distances are

*Dx* = 2 ft (0.6 m) *Dy* = 1 ft (0.3 m)

##### THIV

Finally, the Theoretical Head Impact Velocity (THIV) is the relative velocity at time *T*, i.e.,

*THIV* = ⎡⎣*v*2 (*T* )+ *v*2 (*T* )⎤⎦

*x y*

1 2

THIV shall be reported in ft/s (m/s).

F2.3 POST-IMPACT HEAD DECELERATION (PHD)

Post-impact Head Deceleration (PHD) is the maximum value of the acceleration fi ltered by a 10 Hz low-pass fi lter, occurring after the time *T* of the collision of the theoretical head. If F10 represents the fi ltering, then:

( ( 2 2 )1 2 ) ( )

*PHD* = *MAX*

F10

&*x*&*c* + &*y*&*c*

for *t* > *T*

PHD shall be reported in G units.

F2.4 SUMMARY OF PROCEDURE TO COMPUTE THIV AND PHD

1. Record vehicular accelerations and yaw rate, and store in digital form at the sample rate *S*; let the

data in the three record fi les be *k* &*x*& , *k* &*y*& , and *k* Ψ& (*k* = 1, 2,..., *N* ) . The time interval between two sub-

*c c*

sequent data in the record fi le is *h* = *k t* − *k* −1*t* = 1/ *S* . For example, if *S* = 500 samples per second, then

*h* = 2 ms.

1. Integrate the yaw rate by the recurrent formula (from Equation F2-2):

1 2 1

1Ψ& + 2 Ψ&

*k* +1 *k*

*k* Ψ& + *k* +1Ψ&

Ψ = Ψ0 ;

Ψ = Ψ + *h*

2

; ... ;

Ψ = Ψ + *h*

2

1. Compute vehicular acceleration in ground reference (from Equation F2-3):

*k X*&&

= *k* &*x*&

cos *k* Ψ − *k* &*y*&

sin *k* Ψ

*kY*&&

= *k* &*x*&

sin *k* Ψ + *k* &*y*&

cos *k* Ψ

*c c c c c c*

1. Integrate vehicular acceleration in ground reference (from Equations F2-4 and F2-9):

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⎧1Δ*X*&

= 0;

*k* +1Δ*X*&

= *k* Δ*X*&

*k* Δ*X*&&

+ *h*

+ *k* +1Δ*X*&&

⎪ *c c c*

⎪

⎨

⎪

2

*k* Δ*Y*&& + *k* +1Δ*Y*&&

*c c*

⎪1Δ*Y*& = 0;

*k* +1Δ*Y*& = *k* Δ*Y*& + *h c c*

⎩ *c c c* 2

⎧1Δ*X*

⎪

*b*

⎪

⎨

= *X*0 ;

*k* +1Δ*X*

= *k* Δ*X* − *h*

*b b*

*k* Δ*X*&

+ *k* +1Δ*X*&

*c c*

2

⎪

⎪1Δ*Y*

= 0;

*k* +1Δ*Y*

= *k* Δ*Y*

*k* Δ*Y*& + *k* +1Δ*Y*&

− *h*

*c c*

⎩ *b b b* 2

1. Compute relative position and relative velocity of the theoretical head as functions of time (from the last two equations in item 4):

⎧ *k x*

(*t* )= *k* Δ*X*

cos *k* Ψ + *k* Δ*Y* sin *k* Ψ

⎪ *b b b*

⎨

⎪ *k y*

(*t* )=− *k* Δ*X*

sin *k* Ψ + *k* Δ*Y* cos *k* Ψ

⎩ *b b b*

⎧ *k v*

=− *k* Δ*X*&

cos *k* Ψ− *k* Δ*Y*& sin *k* Ψ+ *k y*

*k* Ψ&

⎪ *x c c b*

⎨

⎪ *k v*

=− *k* Δ*X*&

sin *k* Ψ− *k* Δ*Y*& cos *k* Ψ& − *k y*

*k* Ψ&

⎩ *y c c b*

1. Find the minimum value of *j* for which one of the three equalities is satisfi ed:

*j j j*

*xb* = *Dx* + *X* 0 ; or

*yb* = *Dy* ; or

*yb* = −*Dy*

1. Compute the following:

*THIV* = ⎡

*x*

*j v*2 +

1

*j* 2 ⎤ 2

*v*

*y*

⎣ ⎦

1. Compute the resultant vehicular acceleration in G as a function of time:

*k A* **=**

1 *k* &*x*&2 **+**

G

*c*

(

*k* &*y*&2 1 2

*c*

1. Filter the sequence *kA* with a digital Butterworth low-pass fi lter, having a cut-off frequency of 10 Hz, a roll-off of 48 dB/octave, and apply a 10-ms moving average; PHD is the maximum of such fi ltered sequence.

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### F3 A GUIDE TO THE MEASUREMENT OF THE ACCELERATION SEVERITY INDEX (ASI)

F3.1 PROCEDURE

The Acceleration Severity Index (ASI), developed by TTI (90), is a function of time, computed with the following formula:

 1/2

ASI(*t*) = [(*ax*/*âx*)2 + (*ay*/*ây*)2 + (*az*/*âz*)2]

(Eq. F3-1)

where *a*ˆ*x* , *a*ˆ*y* , and *a*ˆ*z* are limit values for the components of the acceleration along the body axes *x*, *y*, and *z*; *ax* , *ay* , and *az* are the components of the acceleration of a selected point *P* of the vehicle, averaged over a moving time interval δ = 50 ms, so that:

*a* = 1

*t* +δ

*a dt*;

*a* = 1

*t* +δ

*a dt*;

*a* = 1

*t* +δ

*a dt*

δ ∫*t*

δ ∫*t*

δ ∫*t*

(Eq. F3-2)

*x x y y z z*

The index ASI is intended to give a measure of the severity of the vehicular motion during an impact for a person seated in the proximity of point *P*.

Averages computed in Equations F3-2 are equivalent to what would be obtained by a low-pass fi lter, and take into account the fact that vehicular accelerations can be transmitted to the occupant body through relatively soft contacts which cannot pass the highest frequencies. Direct use of vehicular accelerations, even if averaged, implies that the parts of occupant body that can be injured are con- tinuously in contact with some part of the vehicle.

Note that Equation F3-1 is a basic interaction formula of three variables. If any two components of vehicular acceleration are null, ASI reaches its limit value of 1 when the third component reaches its limit acceleration. When two or three components are non null, ASI may be 1 with the single com- ponents well below the relevant limits. Limit accelerations are interpreted as the values below which occupant risk is very small (light injuries, if any).

In Europe (France, Germany, and Netherlands), for occupants wearing safety belts, the generally used limit accelerations are:

*a*ˆ*x* = 12 G,

*a*ˆ*y* = 9 G,

*a*ˆ*z* = 10G

(Eq. F3-3)

where G = 32 ft/s2 (9.81 ms–2) is the acceleration of Earth gravity at sea level.

With the above defi nition, ASI is a nondimensional quantity, i.e., a scalar function of time and, in general, of the selected vehicular point, having only positive values. Occupant risk is assumed to be proportional to ASI. Therefore, the maximum value attained by ASI in a collision is assumed as a single measure of the severity, or:

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ASI = max[ASI(*t*)] (Eq. F3-4)

Vehicular accelerations in the *x*, *y*, and *z* directions are measured at or near the center of mass of the vehicle (see Section 4.3.2 for recommended procedures to determine accelerations in the *x* and *y* directions at the center of mass if the accelerometers cannot be placed at or near the center of mass).

F3.2 SUMMARY

In summary, the following steps are used to compute the ASI:

1. Record vehicular accelerations in the *x*, *y*, and *z* directions at or near the vehicle’s center of mass (see Section 4.3.2 if accelerometers can not be placed at or near the center of mass). In general, accelerations are stored on a magnetic tape as three series of *N* numbers, sampled at a certain

sampling rate *S* (samples/s).

For such three series of measures where acceleration of gravity (G) is the unit of measurement, compute:

1*a* , 2*a* , ... , *k* −1*a* , *k a* , *k* +1*a* , ... , *N a*

*x x x x x x*

1*a* , 2*a*

, ... , *k* −1*a*

, *k a*

, *k* +1*a*

, ... , *N a*

*y y y y y y*

1*a* , 2*a* , ... , *k* −1*a* , *k a* , *k* +1*a* , ... , *N a*

*z z z z z z*

1. Find the number *m* of samples in the averaging window δ = 0.05 s; thus, *m* = INT(δ\*S) = INT(0.05\*S), where INT(R) is the integer nearest to *R*. For example, if *S* = 500 samples per second, *m* = 25.
2. Compute the average accelerations from Equation F3-2:

*k a* = 1 (*k a*

+ *k* +1*a*

+ *k* + 2 *a* + K + *k* + *m a*

)= 1

*k* + *m*

*j a*

*x x x x x* ∑ *x*

*m m j* =*k*

*k a* = 1 (*k a*

+ *k* +1*a*

+ *k* + 2 *a* + K + *k* + *m a*

)= 1

*k* + *m*

*j a*

1. *y y y y* ∑ *y*

*m m j* =*k*

*k a* = 1 (*k a*

+ *k* +1*a*

+ *k* + 2 *a* + K + *k* + *m a* )= 1

*k* + *m*

*j a*

1. *z z z z* ∑ *z*

*m m j* =*k*

Functions of time

*kt* = *h*(*k* + *m*/2)

1. Compute ASI as a function of time from Equation F3-1:

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*k* ASI = ⎡(*k a*

12)2 + (*k a*

9)2 + (*k a*

1

10)2 ⎤ 2

⎣⎢ *x y z* ⎥⎦

1. Find ASI as the maximum of the series of the *k*ASI.

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