Weyl Fractional Derivative of Multivariable Polynomials and I- Function

Neelam Pandey¹, Harish Kumar Mishra²* and Kshamapati Tripathi³

¹Department of Mathematics, Govt. Model Science College, Rewa (M.P.), India
²S.V. M. Science and Technology, Lalganj, Pratapgarh, India
³Department of Mathematical Sciences, A.P.S. University, Rewa (M.P.), India

Email: mishraharish9@gmail.com

ABSTRACT

In this research work, we establish a theorem on Weyl fractional derivative of the product of multivariable polynomials and I- function in the literature of special functions. The results are obtained in the compact form containing the multivariable polynomials. Some special cases of our theorem have been discussed.

KEYWORDS- Weyl fractional derivative operator, multivariable polynomials and I-function.

*Corresponding author
Harish Kumar Mishra
S.V. M. Science and Technology,
Lalganj, Pratapgarh, India
Email: mishraharish9@gmail.com
INTRODUCTION

Recently, for modeling of relevant systems in various fields of sciences and engineering, such as fluid flow, diffusion, relaxation, oscillation, anomalous diffusion, polymer physics, chemical physics, propagation of seismic waves, etc. see, Glöckle and Nonnenmacher\(^1\), Mainardi\(^2\,3\), Miller and Ross\(^4\), Kilbas et al.\(^5\) and others.

The I-function of the one variable is defined by Saxena\(^6\) and we will represent here in the following manner:

\[
I[z]=I_{p_r,q_r}^{m_n,p_l,q_l}[z] = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} \prod_{j=1}^{n} \prod_{i=1}^{p_l} \prod_{r=1}^{q_l} \frac{\Gamma(1-a_j + e_r s)}{\Gamma(b_j - f, s)} ds,
\]

where \(i = \sqrt{-1}\), \(z(\neq 0)\) is a complex variable and (1.2) \(z^s = \exp \left[ s \{ \log |z| + i \arg z \} \right] \). In which \(\log |z|\) represent the natural logarithm of \(|z|\) and \(\arg |z|\) is not necessarily the principle value. An empty product is interpreted as unity. Also,\(^{10}\)

\[
\theta(s) = \frac{\prod_{j=1}^{n} \prod_{i=1}^{p_l} \prod_{r=1}^{q_l} \Gamma(b_j - f, s)}{\prod_{j=1}^{n} \prod_{i=1}^{p_l} \prod_{r=1}^{q_l} \Gamma(1-a_j + e_r s)}
\]

\(m, \ n, \ p, \) and \(q, \forall i \in (1, \ldots r)\) are non-negative integers satisfying \(0 \leq n \leq p, 0 \leq m \leq q, \forall i \in \{1, \ldots r\}\). \(a_j, e_r, b_j, f, i = 1, \ldots, r\) and \(f, (j = 1, \ldots, q, i = 1, \ldots r)\) are assumed to be positive quantities for standardization purpose. Also \(a_j, (j = 1, \ldots, p, i = 1, \ldots r)\) and \(b_j, (j = 1, \ldots, q, i = 1, \ldots r)\) are complex numbers such that none of the points.

\[
S = \{(b_n + v)|f_n, h = 1, \ldots, m; v = 0,1,2,\ldots\}
\]

which are the poles of \(\Gamma(b_n - f, s), h = 1, \ldots, m\) and the points\(^{10}\)

\[
S = \{(a_i - n - 1)|e_l, l = 1, \ldots, n; \eta = 0,1,2,\ldots\}
\]

Which poles are of \(\Gamma(1 - a_i + e, s)\) coincide with one another, i.e. with

\[
e_l (b_n + v) \neq b_n (a_i - \eta - 1).
\]
for \( \nu, \eta = 0, 1, 2, \ldots; h = 1, \ldots, m; l = 1, \ldots, n \).

Further, the contour \( L \) runs from \(-i\omega\) to \(+i\omega\). Such that the poles of \( \Gamma(b_n - s) , h = 1, \ldots, m \); lie to the right of \( L \) and the poles \( \Gamma(1-a_i + e_j s), l = 1, \ldots, n \) lie to the left of \( L \). The integral converges, if \( |\arg z| < \frac{1}{2} B \pi, B > 0, A \leq 0 \), where

\[
A = \sum_{j=1}^{n} e_j - \sum_{j=1}^{n} f_j \quad \text{and} \quad (1.7)
\]

\[
B = \sum_{j=1}^{n} e_j - \sum_{j=1}^{n} f_j + \sum_{j=1}^{n} f_j - \sum_{j=1}^{n} f_j , \quad \forall i \in (1, \ldots, r) \quad (1.8)
\]

Let \( A \) denote a class of good functions. By good function \( f \), we mean Miller\(^7\) a function which is everywhere differentiable any number of times and if it is all of its derivatives are \( 0(x^{-\nu}) \), for all \( \nu \) as \( x \) in increases without limit. We define the Weyl fractional derivatives of a function \( g(z) \) as follows:-

Let \( g \in A \), then for \( q < 0 \),

\[
\zeta^q W_n g(z) = \frac{(-1)^q}{\Gamma(-q)} \int_\epsilon^\infty (u-z)^{-q-1} g(u)du. \quad (1.9)
\]

For \( q \geq 0 \)

\[
\zeta^q W_n g(z) = \frac{d^n}{dz^n} (\zeta^q W_n g(z)), \quad (1.10)
\]

Where \( n \) being positive integer, such that \( n > q \).

The general class of multivariable polynomials is defined by Srivastava and Garg\(^8\).

\[
S^h_{L} [x_1, \ldots, x_r] = \sum_{k_1, \ldots, k_r = 0}^{h_1 + \ldots + h_r; \leq L} (-L)_{h_1 + \ldots + h_r} A(L; k_1, \ldots, k_r) \frac{x_1^{k_1}}{k_1!} \ldots \frac{x_r^{k_r}}{k_r!}, \quad (1.11)
\]

Where \( h_1, \ldots, h_r \) are positive integers and the co-efficient \( A(L; k_1, \ldots, k_r) \), (\( L; h_1 \in N; i = 1, \ldots, r \)) are arbitrary constant, real or complex.

Evidently the case \( r = 1 \) of the polynomials(1.11).

Would correspond the polynomials given by Srivastava\(^9\).
\[ S_L^k[x] = \sum_{l=0}^{(L-k)} \frac{(L-k)!}{k!} A_{L-k} x^k \{ L \in N = (0,1,2,\ldots) \}, \tag{1.12} \]

where \( h \) is arbitrary positive integers and the co-efficient \( A_{L-k}(L,k \geq 0) \) are arbitrary constant, real or complex.

2. MATHEMATICAL PRE-REQUISITES - To establish the main result, we need the following integral of the H-function by Saigo

\[
\int_x^{+\infty} t^{\sigma-1} (t-x)^{\rho-1} \prod_{j=1}^{m,n} \left[ (a_j, e_j)_{n+1,p_j} ; (a_{j+}, e_{j+})_{n+1,p_j} \right] dt
\]

\[
= x^{\sigma-1} \prod_{j=1}^{m,n+1} \left[ (1-\rho, \sigma, \mu+\nu, (a_j, e_j)_{n+1,p_j} ; (a_{j+}, e_{j+})_{n+1,p_j} \right] \tag{2.1}
\]

Where

(i) \( \rho, \sigma \) are complex numbers and \( \mu, \nu \) are positive real numbers,

(ii) \( \arg z < \frac{1}{2} \pi \), \( A \) defined as \( A = \sum_{j=1}^{p} e_j - \sum_{j=1}^{q} f_j \),

(iii) \( \min \left[ Re \left( \frac{1-\rho-\sigma}{\mu-\nu} \right) \right] \leq \min \left[ Re \left( \frac{b_j}{f_j} \right) \right] \geq \max \left[ \max \left[ Re \left( \frac{a_j-1}{e_j} \right) \right] \right]. \]

3. WEYL FRACTIONAL DERIVATIVE OF MULTIVARIABLE POLYNOMIALS AND I- FUNCTION-

THEOREM. Let \( m, n, p, q \) be non-negative integers such that \( 0 \leq n \leq p, 0 \leq m \leq q \), and

\[
\sum_{j=1}^{p} e_j - \sum_{j=m+1}^{q} f_j > 0 \]

together with the set of conditions (i) – (iii) given with equation (2.1). Then, for all value of \( q \),

\[ W_{\alpha}^{q} \left\{ x^{\rho-1} (z-x)^{\sigma-1} S_{h^1 \ldots h^r}^L \left[ c_1 x^{h_1} , \ldots , c_r x^{h_r} \right] \right\} \]
\[
(\frac{-1}{\Gamma(-q)} \sum_{k_1, \ldots, k_r = 0}^{h_1 + \cdots + h_k = L} (-L) \cdot A(L; k_1, \ldots, k_r) \cdot \frac{c_{k_1}}{k_1!} \cdots \frac{c_{k_r}}{k_r!} \cdot \frac{(-1)^{q+r+\sigma-1} \cdot d^r}{\Gamma(r-q) \cdot \frac{z}{d^r}} \cdot z^{\sigma-q-\sum_{i=1}^{r} k_i} \cdot \frac{2 - \sigma + q \cdot v, (a_j, e_j), (a_j, e_j)_{m+1,p}, (1 - \rho - \sum_{i=1}^{r} k_i \cdot \delta_j, \mu)}{(2 + q - \rho - \sigma - \sum_{i=1}^{r} k_i, \mu + \nu, (b_j, f_j), (b_j, f_j)_{m+1,q})} 
\]

PROOF - Taking left hand side of equation (3.1) and using equation (1.11), we get

\[
\frac{W_z}{\pi} \cdot \frac{x^{\sigma-r-1} \cdot (z-x)^{\sigma-1}}{\pi} \sum_{k_1, \ldots, k_r = 0}^{h_1 + \cdots + h_k = L} (-L) \cdot A(L; k_1, \ldots, k_r) \cdot \frac{c_{k_1}}{k_1!} \cdots \frac{c_{k_r}}{k_r!} \cdot \frac{2 - \sigma + q \cdot v, (a_j, e_j), (a_j, e_j)_{m+1,p}, (1 - \rho - \sum_{i=1}^{r} k_i \cdot \delta_j, \mu)}{(2 + q - \rho - \sigma - \sum_{i=1}^{r} k_i, \mu + \nu, (b_j, f_j), (b_j, f_j)_{m+1,q})} 
\]

Now using equation (1.9) and definition of I- function, easily we can find the proof of equation (3.1).

For q ≥ 0 invoking the definition (1.10) the relation (3.2) further reduces to

\[
\sum_{k_1, \ldots, k_r = 0}^{h_1 + \cdots + h_k = L} (-L) \cdot A(L; k_1, \ldots, k_r) \cdot \frac{c_{k_1}}{k_1!} \cdots \frac{c_{k_r}}{k_r!} \cdot \frac{(-1)^{q+r+\sigma-1} \cdot d^r}{\Gamma(r-q) \cdot \frac{z}{d^r}} \cdot z^{\sigma-q-\sum_{i=1}^{r} k_i} \cdot \frac{2 - \sigma - r + q \cdot v, (a_j, e_j), (a_j, e_j)_{m+1,p}, (1 - \rho - \sum_{i=1}^{r} k_i \cdot \delta_j, \mu)}{(2 + q - \rho - \sigma - r - \sum_{i=1}^{r} k_i, \mu + \nu, (b_j, f_j), (b_j, f_j)_{m+1,q})} 
\]

In replacing of (q - r) by q, we may obtain again

\[
\frac{(-1)^{q+r+\sigma-1}}{\Gamma(-q)} \cdot \sum_{k_1, \ldots, k_r = 0}^{h_1 + \cdots + h_k = L} (-L) \cdot A(L; k_1, \ldots, k_r) \cdot \frac{c_{k_1}}{k_1!} \cdots \frac{c_{k_r}}{k_r!} \cdot \frac{2 - \sigma + q \cdot v, (a_j, e_j), (a_j, e_j)_{m+1,p}, (1 - \rho - \sum_{i=1}^{r} k_i \cdot \delta_j, \mu)}{(2 + q - \rho - \sigma - \sum_{i=1}^{r} k_i, \mu + \nu, (b_j, f_j), (b_j, f_j)_{m+1,q})} 
\]
4. SPECIAL CASE - If we put r=1 in the general call of multivariable polynomials given by Srivastava and Garg\(^8\) reduces to the polynomials given by Srivastava(1972) and \(I\)-function reduces into Fax's H\\-function as follows:

\[
\sum_{k=0}^{[|L|]} \frac{(-1)^{k+1}}{|k|!} A_{L,k} L^{m+1,q+1} \left[ y^{1/2} \right]^{\left(2-q-\sigma-k, \mu+\nu\right)} (a_j, e_j)_{1,p}, (b_j, f_j)_{1,q}
\]

(4.1)

Replacing \(\nu\) by \(-\nu\) equation (4.1) correspond to the following result according as \(\mu > \nu\), \(\mu < \nu\) and \(\mu = \nu\), i.e. for \(\mu > \nu\)

\[
\sum_{k=0}^{[|L|]} \frac{(-1)^{k+1}}{|k|!} A_{L,k} L^{m+1,q+1} \left[ y^{1/2} \right]^{\left(2-q-\sigma-k, \mu+\nu\right)} (a_j, e_j)_{1,p}, (b_j, f_j)_{1,q}
\]

(4.2)

For \(\mu < \nu\)

\[
\sum_{k=0}^{[|L|]} \frac{(-1)^{k+1}}{|k|!} A_{L,k} L^{m+1,q+1} \left[ y^{1/2} \right]^{\left(2-q-\sigma-k, \mu+\nu\right)} (a_j, e_j)_{1,p}, (b_j, f_j)_{1,q}
\]

(4.3)

and \(\mu = \nu\)

\[
\sum_{k=0}^{[|L|]} \frac{(-1)^{k+1}}{|k|!} A_{L,k} L^{m+1,q+1} \left[ y^{1/2} \right]^{\left(2-q-\sigma-k, \mu+\nu\right)} (a_j, e_j)_{1,p}, (b_j, f_j)_{1,q}
\]

(4.4)

Finally writing \(-\mu\) instead of \(\mu\), equation (4.1) yields the following results according as \(\mu > \nu\), \(\mu < \nu\) and \(\mu = \nu\) respectively.
\[
W_{m,n}^{\mu} \left\{ x^{\rho-1} (z-x)^{\sigma-1} S_L^k \left[ x^k \right] \right\} \times H_{\mu}^{m,n} \left\{ y x^{\rho-1} \right\} \left( (a_i, e_i)_{L,p} \right) \\
= (-1)^{\rho+\sigma-1} \frac{\Gamma(-q)}{\Gamma(-q)} \sum_{k=0}^{l+1} \left( \frac{L}{k} \right) (-1)_k A_{L,k} H_{\mu+1, q+1}^m \left\{ y z^{\mu-1} \right\} \left( (2-\sigma+q, \nu)_{L, p} \right) \left( (2+q-\rho-\sigma-k, \mu)_{L, q} \right) \\
\text{for } \mu < \nu
\]

\[
W_{m,n}^{\mu} \left\{ x^{\rho-1} (z-x)^{\sigma-1} S_L^k \left[ x^k \right] \right\} \times H_{\mu}^{m,n} \left\{ y x^{\rho-1} \right\} \left( (a_i, e_i)_{L,p} \right) \\
= (-1)^{\rho+\sigma-1} \frac{\Gamma(-q)}{\Gamma(-q)} \sum_{k=0}^{l+1} \left( \frac{L}{k} \right) (-1)_k A_{L,k} H_{\mu+1, q+1}^m \left\{ y z^{\mu-1} \right\} \left( (2-\sigma+q, \nu)_{L, p} \right) \left( (2+q-\rho-\sigma-k, \mu)_{L, q} \right) \\
\text{and for } \mu = \nu
\]

\[
W_{m,n}^{\mu} \left\{ x^{\rho-1} (z-x)^{\sigma-1} S_L^k \left[ x^k \right] \right\} \times H_{\mu}^{m,n} \left\{ y x^{\rho-1} \right\} \left( (a_i, e_i)_{L,p} \right) \\
= \frac{\Gamma(2-\rho-k-\sigma+q)}{\Gamma(-q)} \left( -1 \right)^{\rho+\sigma-1} \frac{\Gamma(-q)}{\Gamma(-q)} \sum_{k=0}^{l+1} \left( \frac{L}{k} \right) (-1)_k A_{L,k} H_{\mu+1, q+1}^m \left\{ y z^{\mu-1} \right\} \left( (2-\sigma+q, \nu)_{L, p} \right) \left( (2+q-\rho-\sigma-k, \mu)_{L, q} \right) .
\]

DISCUSSION

We have obtained the results namely theorem and special cases which satisfied all the conditions mention in the statement.

REFERENCES


